Computing Machines

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With friendly support of

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Preface

The computer has always enabled statisticians to carry out their tasks effectively and through subsequent developments in digital technology, with increasing efficiency. Computer technology has also enabled statisticians to identify new areas of activity and to discover and define new tasks or areas of research. In other words, the computer has been the driving force for statisticians to go into new, untapped areas such as *bootstrapping*. In this sense the computer has been the secret of statisticians' success.

Bootstrapping technologies are applied in areas such as computing, physics, law and even linguistics. However, the term refers to quite different applications as the booting process to start a computer or the theory as to why children can learn a language intuitively. But these methods have one thing in common: they refer to a self-starting process that may proceed without additional input.

Etymologically speaking, the term bootstrap refers to a variation of Rudolf Erich

Raspe's The Surprising Adventures of Baron Munchausen. While the published version states that Munchausen pulls himself and his horse out of a swamp by using his pigtail, in another variation he does so by using his own bootstrap.

Figure 1: Baron von Munchausen

The *statistical bootstrap* method always relies on random sampling and thus, would not be feasible in practice without a programmable computing machine. Not surprisingly, it was introduced by Bradley Efron in 1979 and published in Efron (1992) during a time when the first personal computers such as the *Com-*

modore PET were already on the market. Obviously, the bootstrap technology advanced further due to computational development as demonstrated in Härdle et al. (2015).

It is not only through bootstrap resampling techniques that statistics has made great strides, the highly complex methods of non- and semi-parametric additive models have been made possible through computers. In other scientific disciplines too, computers have had a massive impact: big data, smart data, remote sensing, global land surveys, digital geography and digital cartography are all areas of science that have been established and have thrived through the use of computers.

However, this book is not focused on land-set data or computing in medicine, but it will concentrate on computing machines and how they led to new statistical methods. This book showcases parts of the C.A.S.E. computer museum, an official scientific collection of Humboldt-Universität zu Berlin. Furthermore, this book outlines the development from manually preprocessed and edited data, as found on punched cards, to today's status quo, where data is generated and stored every time we visit a webpage or buy food at a grocery shop.

To highlight how personal and professional development intermingles with the state-of-the-art computers of their time, Wolfgang Karl Härdle, Professor at the Ladislaus von Bortkiewicz Chair of Statistics at Humboldt-Universität zu Berlin shares three personal stories regarding computers as follows.

Commodore PET, 1977

In the early 1980s Wolfgang Härdle brought this computer jointly with a colleague from DKFZ (German Cancer Research Center) Heidelberg. In BASIC they programmed a binary-tree inventory database for a retail-shoe-shop. With this BASIC program, which was in use until the mid-1990s, the shop could efficiently control its inventory and develop its sales strategies.

Apple Macintosh Classic, 1990

In 1990 Wolfgang Härdle launched The Journal of Computational Statistics

(Physika-Verlag, Springer). The organisational aspects of the journal contained authors, titles of papers and submission details which were all handled by this computer using AppleWorks software. The computer was later connected to a bigger second monitor and was used further for this role until 1993.

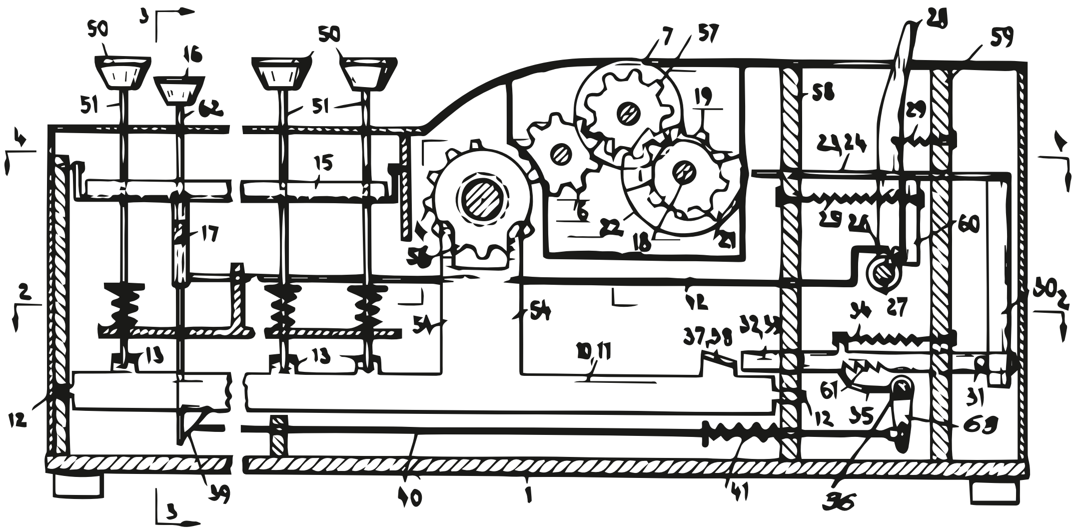
Toshiba T5200/100, 1991

This computer was used by Wolfgang Härdle in a university lecture to interactively demonstrate multivariate statistical analysis using GAUSS. Students would come up with a co-variance matrix and the GAUSS program would calculate the principle components. The computer was also significant in the development of the third version of the XploRe program.

The *C.A.S.E.* computer museum was founded in 2000 with the aim of preserving the history of computational statistics by keeping former computers, in many cases with statistical software, in an operative state. As of May 2016, the museum has more than 150 objects, including over 50 desktops, around 45 portables and mechanical and electronic calculators plus a large amount of peripheral objects. Regarding the software, running versions of XploRe, Matlab, Mathematica and SPSS have also been preserved.

To honour the approach of transparent and reproducible research, we submit programming codes used in this publication to the platform "Quantnet" on www.quantlet.de. More specifically, the Quantnet-Github platform introduced by Borke and Neuhoff (2015) allows each code to be uniquely identified by its specific id following the quantlet logo.

Mechanical Calculators



Mankind has always strived for devices to simplify their day-to-day activities. Thus, it is only natural and logical that the abacus appeared as early as 2700 - 2300 BC in ancient Mesopotamian as stated by Ifrah (2001). Unlike modern societies, the calculations on these Sumerian abaci were represented in the sexagesimal number system with a base of sixty instead of a base of ten, in the decimal system common today. Calculating devices such as these were also known in other ancient cultures like Egypt, Persia, Greece and Rome as well as in wider parts of Asia and Native America.

While numerous different counting frames were developed all over the word, the Chinese *Suanpan* is a particularly interesting case. While it is broadly reported on for example, the website Beijing Tourism (2014) as being listed as an intangible cultural heritage by *UNESCO* since 2013, this is only partly true. The calculating device itself is not listed but the knowledge of how to perform calculations with it is listed, commonly referred to as *Zhusuan*, as stated in UNESCO (2013). By utilising the knowledge of *Zhusuan* and a *Suanpan*, one can perform the four basic arithmetic operations as well as the calculation of square cube roots. Furthermore, experienced users were able to beat adaptors of early electronic

Figure 2: Chinese abacus

pocket calculators time and precisionwise. The upper part of the abacus, the *heaven*, is seperated from the lower part, the *earth*, by a bar. The *heaven* beads carry a five while the *earth* beads carry a one in their columns, respectively. Due to its decimal system, the *Suanpan* can perform calculations with virtually any precision as the number of columns may be increased without a change in the calculation methods.

While the calculating techniques in ancient China were highly sophisticated, the beads still had to be moved manually. The carrying mechanism in particular was not mechanical but was done by a trained operator. Several milestones in the development of automatons were set by the ancient Greeks, Egyptians and Romans as described in Moon (2009). Examples of the early mechanical finesse of ancient cultures are the *odomoter* to measure distances, first used by *Heron of Alexandria* who probably lived between 10 BC and 70 AD and mechanical clocks.

The first attempts to develop mechanical calculators took place in Europe in the 17th century. During this period, both *Wilhelm Schickard* and *Blaise Pascal* built the first known numeral wheel registers independently of each other. *Wilhelm Schickard* (22 April 1592 – 24 October 1635) was a professor of Hebrew and Astronomy at the University of Tübingen. Falk (2014) describes how Schickard wrote to the astronomer *Johannes Kepler* about his invention in 1623, a *calculating clock*. Examination of Schickard's original drawings and a replica produced by Prof. Bruno von Freytag Löringhoff of the University of Tübingen in 1960, verifies that the machine could add, subtract and multiply. A wheel was successively rotated to add numbers and the principle of the ancient

Roman odometer was used as a tenth-carry mechanism. However, in comparison to later machines it had several shortcomings. For instance, Falk (2014) states that the machine would jam if too many numbers had to be carried simultaneously and furthermore, the machine was not easy to use to the extent that even pen and paper would be easier.

Figure 3: B. Pascal

The French *Blaise Pascal* (19 June 1623 – 19 August 1662) was a mathematician, physicist, inventor and writer. His contributions to the field of mathematics include the tabular presentation for binomial coefficients, commonly known as Pascal's triangle, and several contributions to the theory of probabilities. When his father needed an aid to perform calculations for Cardinal Richelieu's collection of taxes, Pascal became interested in developing automata to add numbers up. His adding machine, also called *Pascaline*, provided two major improvements in comparison to Schickard's clock (compare Falk (2014)). He introduced gears that were able to withstand great stress and thus, were not prone to failure if a large number of digits had to be carried simultaneously. Secondly, his tenth-carrying mechanism was more sophisticated due to a fork-shaped weighted arm on a pivot. However, there was a shortcoming to his mechanism as it did not allow for reverse addition and thus, making subtraction rather clumsy.

Here, the distinction between a calculating machine and adding machine becomes important. In its simplest form, an adding machine uses the turning of gears to add up numbers. This automatically leads it to be able to perform multiplication by repeated addition. However, according to Martin such an adding machine is by no means a calculating machine as it is not able to carry out all four fundamental mathematical operations with great speed.

Further machines were built by *Gottfried Wilhelm von Leibniz* (1 July 1646 - 14 November, 1716), the inventor of differential calculus, and *Philipp Matthäus Hahn* (25 November, 1739 - 2 May, 1790), a German pastor and inventor. Leibniz invented the stepped drum, a cylinder with a set of cogs of incremental length, which was used in building calculators until the invention of the *pinwheel*. However, in comparison to Pascal's machine, the carrying-mechanism was far

Figure 4: Arithmometer

from perfect and was not able to perform multiple carry-operations at the same time.

Hahn built the first dependable calculating machine and set the benchmark for many machines to follow because was able to carry out the four basic arithmetic operations. *Charles Xavier Thomas de Colmar* (5 May, 1785 – 12 March, 1870), a French inventor and entrepreneur, improved Hahn's machine according to his own ideas in 1820 and extensively marketed it to a broader audience.

His machine, called a Thomas machine after his first name or an arithmometer, is by common opinion "the first commercially successful calculator". His stepped drum device was able to carry out the four basic arithmetic operations by using the stopped-wheel principle. These machines were quickly adapted by the insurance industry as suggested by Johnston (1997).

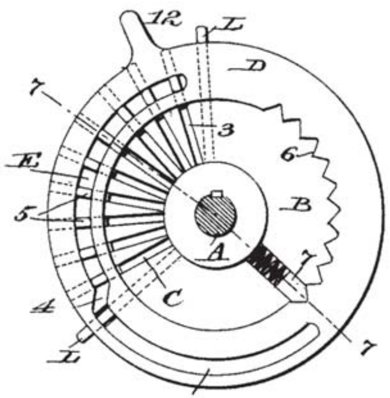


Figure 5: Pinwheel

Later on, the usability of the arithmometer was improved by *Willgodt Theophil Odhner* (10 August, 1845 - 15 September, 1905) in 1873. Odhner was a Swedish engineer and entrepreneur, who invented the *pinwheel* which reduced the cost and size of the device. Figure 5 shows a pinwheel as it was depicted in Odhner's patent application of 1893 under patent number US514725 A. Crank-driven hand pinwheel calculators were still in use in the 1940's as Comrie (1946) points out. Here, the arithmetic operations are carried out by revolving drums. This means that addition is accomplished by turning the crank in one direction while the other direction results in the subtraction of the number. Machines such as these were manufactured by the German companies in particular; for example Brunsviga, which acquired the rights circa 1890, and Rheinmetall.

Due to the development of electricity, it was only a matter of time before hand-driven mechanical calculators were equipped with motors. Falk (2014) states that *Samuel Herzstark* was the first to do so in 1907. However, Comrie (1946) finds that hand machines were often more useful in scientific computing than electro-mechanical calculations due to their flexibility in computations. One example is that a particular Brunsviga model in 1925 was already able to compute $\sum ab$ regardless of signs for each individual product.

Still, as the electric MADAS (Multiplication, Automatic Division, Addition and Subtraction) was also able to compute $\sum ab$ in an automatic fashion, pinwheel machines were soon challenged by automatic full-keyboard machines. Their distinct feature, in contrast to pinwheel machines, is that they were equipped with keyboards with individual columns numbered 1 to 0 for each of the units, tens, hundreds and so on.

Mechanical calculators were still being built until the early 1970s but sales declined due to the rise of purely electronic calculators in the 1960s. ANITA, the first purely electronic desktop calculator was presented by the British Bell Punch company in 1961. It was based on vacuum tube technology which was also employed to build the first computers in the 1940s and 1950s. However, in the mid 1960s, the transistorisation of calculators started and with it, smaller and better calculators could be built, which led to today's pocket calculators.


X x X
DRESDEN

Seidel & Naumann

1906

Germany

Specifications

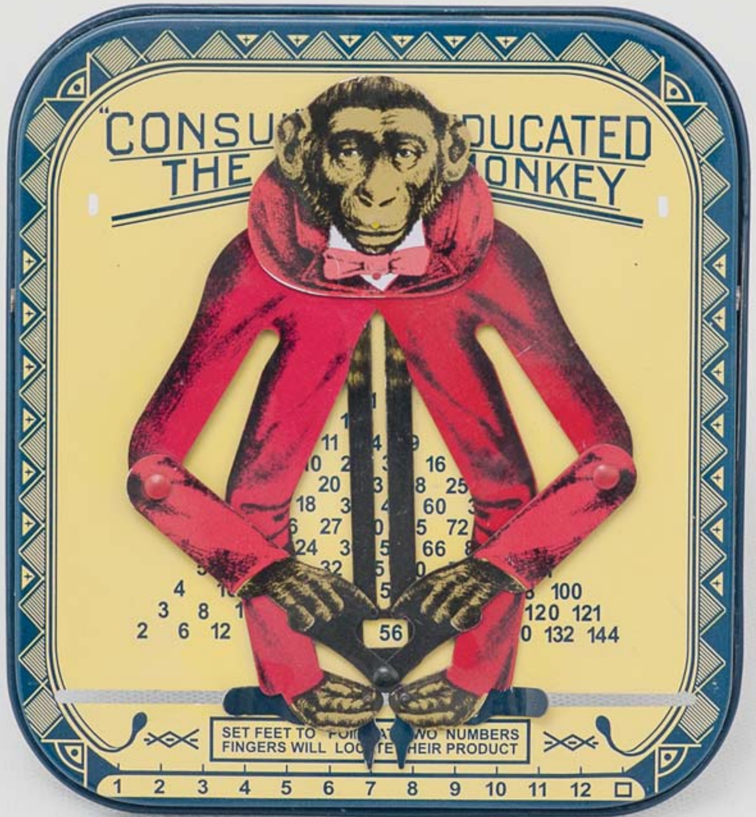
50 x 20 x 14 cm

11kg

Stepped drum

X x X

This stepped drum machine was manufactured as two main models, namely one with setting slides, as seen here, and one with a keyboard. It has a tens-carry in the revolution counter with both, red and white digits. In the model shown, the carriage is arranged on top and there is a lever to differentiate between addition and subtraction. Multiplication and division are carried out by repeated addition and subtraction, respectively.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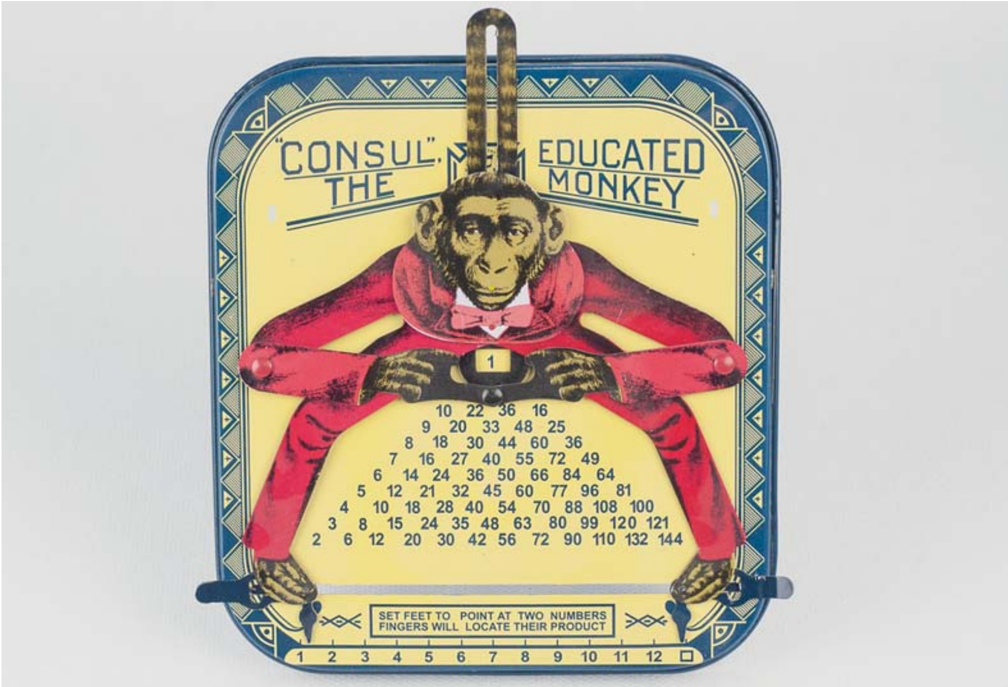
HEIR PRODUCT
56
1 2 3 4 5 6 7 8 9 10 11 12



Educ. Novel.

1916

Consul

This educated monkey, named Consul, was able to perform simple calculations. It could multiply two numbers if its legs were moved to the right. It was invented and patented by William Henry Robertson and produced by the Educational Novelty Company, USA. Of course, it did not have a role as an item of professional equipment for distinguished mathematicians in the early 20th century alongside more refined mechanical calculators, but it was an educational toy for children. Here, we display a more recent replica of an original.

Rheinmetall

1932

Germany

Specifications

41 x 39 x 29 cm

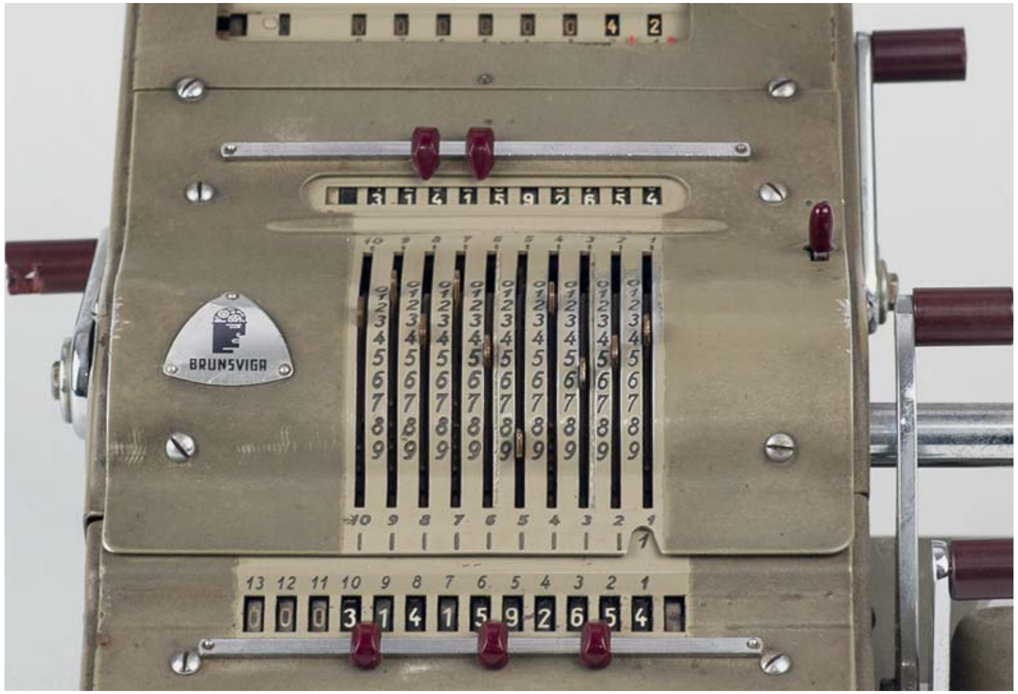
23kg

Stepped drum

Superautomat SAL IIc

SAL is a comfortable, fully automatic electric calculator by Rheinmetall. It came onto the market only five years after MADAS, the first machine that was able to automatically perform division. Similarly to MADAS, it can perform the four mathematical operations fully automatically without repeated hand operations. Furthermore, a SASL model was also available, basically it was a SAL model with an additional summation memory.


BRUNSVIGA
BRUNSVIGA
MASCHINENWERKE AG
BRAUNSCHWEIG



Brunsviga

1952

Germany (West)

Specifications

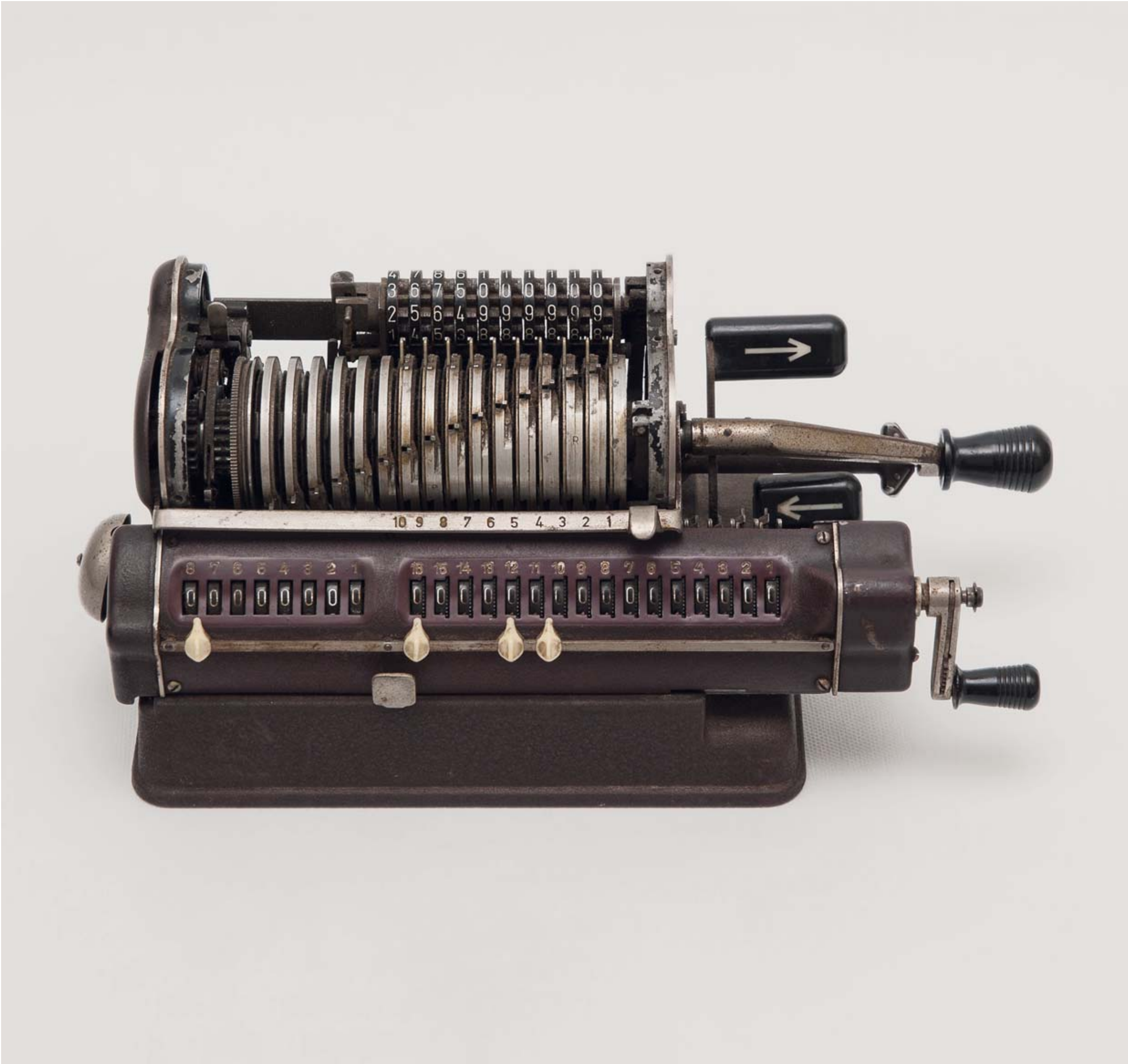
17 x 29 x 25 cm

8kg

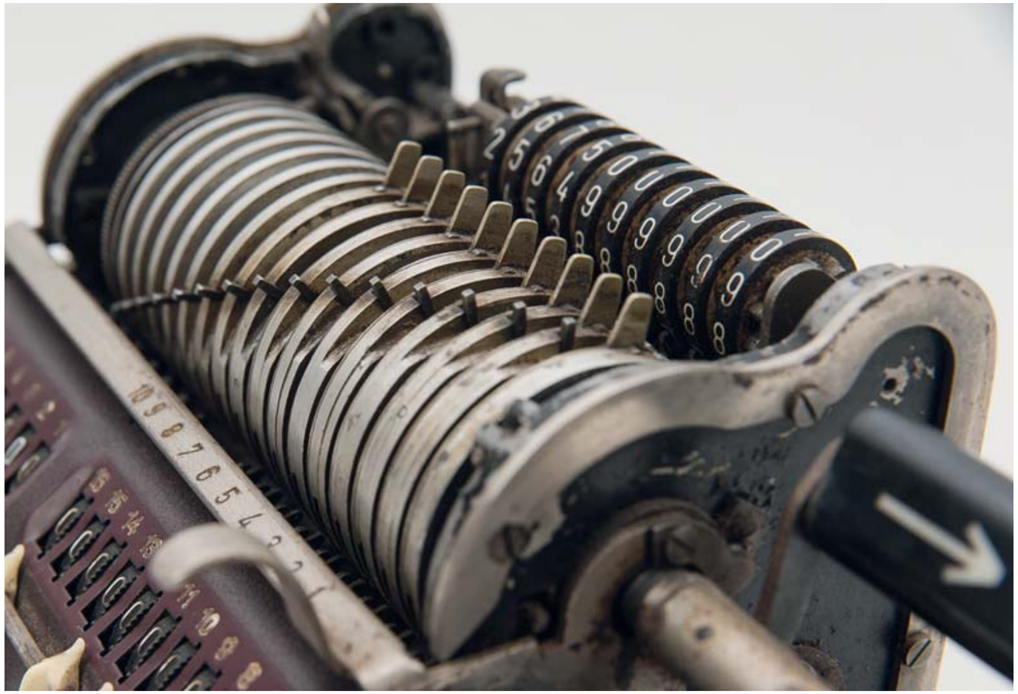
Pinwheel

Brunsviga 13 RK

The Brunsviga line of mechanical calculators was so successful that the manufacturing company, formerly known as Grimme, Natalis & Co., was renamed Brunsviga Maschinenwerke AG. The Brunsviga 13 RK was the most popular model of the whole line, a true mass product, which was available for DM 795. This manually operated pinwheel calculator still works today. A main feature is the register transfer: values may be moved from the accumulator in the input register to set the drums for the next calculation.



10 9 8 7 6 5 4 3 2 1
8 7 6 5 4 3 2 1
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1



Fortuna VEB

1955

Germany (East)

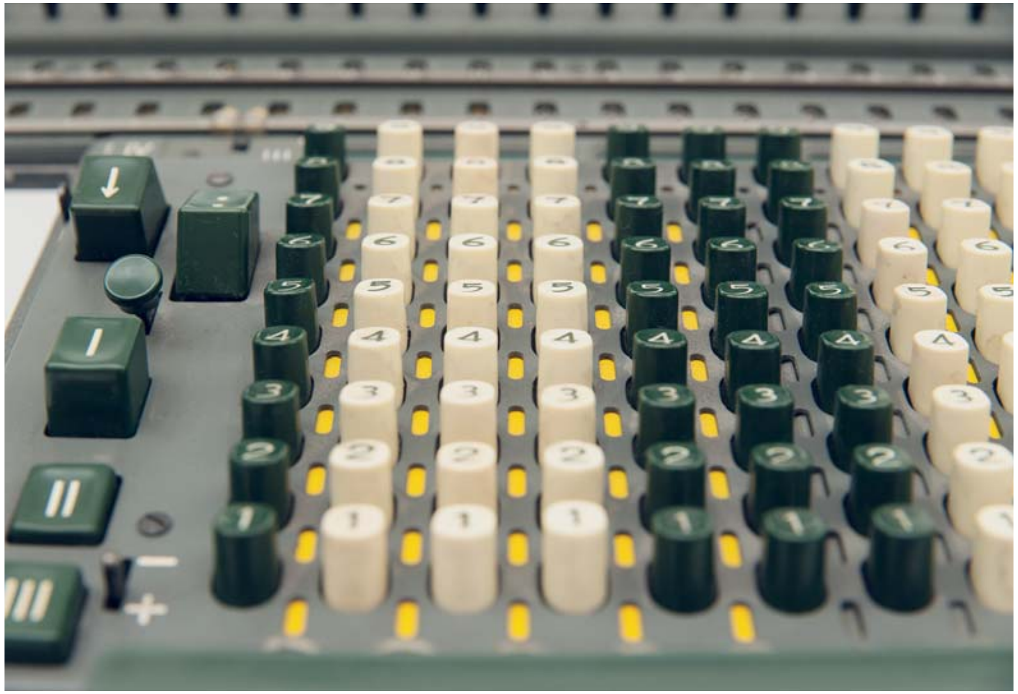
Specifications

Pinwheel

Melitta V/16

The Melitta adding machine from 1955 has nothing to do with today's well-known coffee brand. This pinwheel calculator is, similarly to other machines during that time, based on the Odhner system. Before and during WWII, it was produced by the company Walther in factories in eastern and western Germany. After the division of Germany, the former Walther models were produced by the company Melitta in the GDR while Walther resumed production in the FRG.


ARITHMÉTIC S.A.
Teleph. TRinite 59.20
80, Rue Taitbout PARIS
Div
STOP



H. W. Egli AG

1965

Switzerland

Specifications

Stepped drum

MADAS A 37

The acronym MADAS stands for Multipadalication, Automatic Division, Addition and Subtraction. MADAS was firstly built in 1927 and was the first machine of its kind to perform automatic division. Due to the rise of digital computers, this model also marked the beginning of the end for its company which stopped all activity in 1969. This very calculator was used for the training of statisticians in the area of insurance and finance at the Institute of Statistics Paris University (ISUP). We thank Jacques Chevalier for this contribution.


WALTHER
DE 100

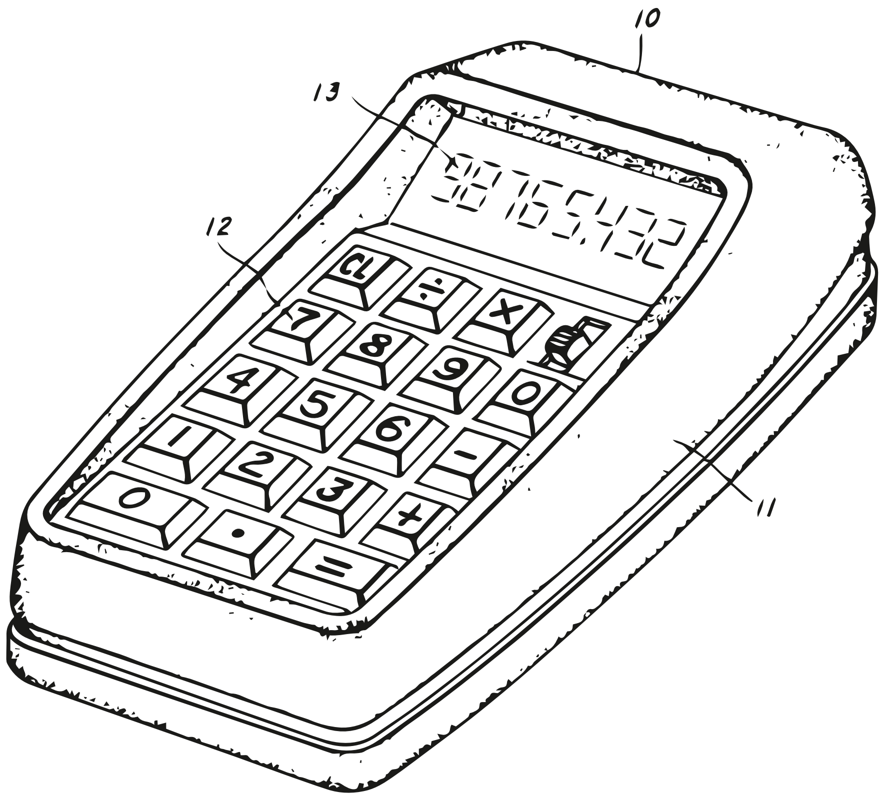
Walther Electronic

1974

Walther DE 100

This desktop calculator was produced by the German company Walther, founded in 1886 in Thuringia. At the beginning Walther produced weapons for hunting, sport shooting, the police and the military. Even James Bond sometimes used a Walther PPK pistol. In the 1920s, Walther began to build calculating machines and by 1964 quarter of a million machines had been produced. Today Walther mainly produces high-performance scanners and document processing systems for the international market.

Pocket Calculators



The history of any computational device is closely linked to the triumph of the electronic calculator. Ifrah (2001) refers to three generations of electronic calculators before the rise of pocket-sized calculators as used today.

The first stage took place in the 1940s and laid the foundation for further developments. However, calculators built during that time were merely experimental and far from a commercial product. Thus, it can be referred to as *experimental stage*. Inventors build on the same *vacuum tube* technology that was also used to assemble the early computers of that time. On the downside, vacuum tubes proved to be as unreliable and costly for calculators as they were for computers. Hence, even though the electronic machines were considerably faster than their mechanical analogs, considerable commercialization did not take place, possibly due to their immense cost and huge size.

Ifrah (2001) describes the second stage as the beginning of the *professionalisation* of the device resulting in an emerging calculator business. The invention of transistors and the resulting printed circuits did not only boost computer development but also took electronic calculators to a whole new level. Until the end of the 1960s, many machines based on this technology were built such as the *Anita* and *Friden 130*. In comparison to modern pocket calculators, they were still rather chunky and resembled cash registers optically.

Figure 6: Transistors

Again, technical advances played a role in a period of miniaturisation and standardisation as described by Ifrah (2001) and resulted in the first pocket calculators. In comparison to older calculators that were either based on mechanical principles or on vacuum tube technology, calculators with integrated circuits decreased in size and weight while becoming more powerful.

The *Busicom LE-120A* by the *Japanese Busicom Corp.* was the first true pocket-sized electronic calculator which came to the market in early 1971. Its U.S. selling price was $395 (around $2,300 today) and it had a quite limited functionality. Nonetheless, it was a breakthrough that smoothed the way for further technological advances. In the early 1970s, more and more electronic pocket calculators were available on the market. However, many

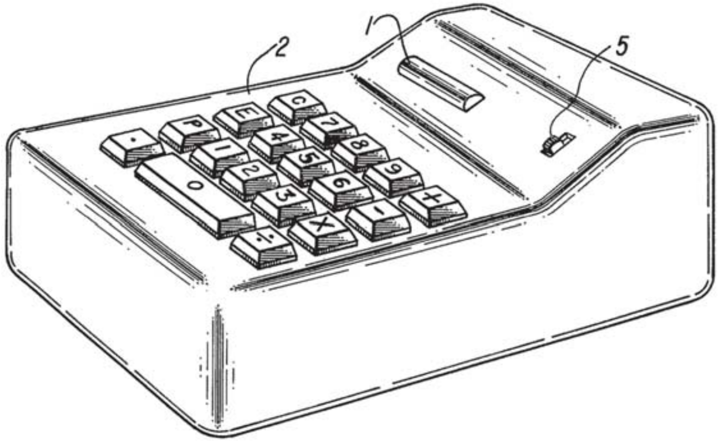


Figure 7: Miniature Electronic Calculator

people continued to use simpler calculators such as a slide rule due to the high cost of the, back then, groundbreaking new technology.

For instance, the company *Texas Instruments*, even today one of the best known producers of pocket calculators, sold their first model *Datamath* in 1972. In 1972, the patent application for *Miniature Electronic Calculator* was also filed by *Texas Instruments* in the US (number 3 819 921), part of the drawing for the patent can be seen in Figure 7. In the very same year Texas Instruments also began to sell the model *SR-10* for a price of $149.95, less than half of


TEXAS INSTRUMENTS
ON
SR-10
1/x
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the price of Busicom's first model. This might have been an early indicator of the ensuing price war in the calculator market as described by Tout (2009). *SR* is an abbreviation for slide rule, an analogous way to perform the same mathematical operations.

Due to large profit margins, the calculator market soon became competitive and prices began to fall. Light-emitting diode (LED) displays were still used instead of the power saving liquid-crystal displays seen today, weighing 262 grams. They were able to show eight digits, the mantissa and two digits that referred to the exponent.

As early as 1972 the magazine *New Scientist* reported on the "price war in the calculator business" in New Scientist (1972) and predicted that several manufacturers would soon withdrawal from the market. It is also recognised that Japanese companies dominated the calculator market from the mid 1960s with their exports increasing by an average of over 200% in the period between 1965 and 1970; obviously this referred to the earlier, non-pocket-sized electronic calculators. In the case of Japanese companies it is notable that many companies with previously different expertise entered the calculator market. One example

brother
PROCAL 508AY
OFF ON K
√ C
7 8 9 ME RM
4 5 6 × ÷
1 2 3 + −
0 · = %

would then be the company *brother* which was predominantly known for their typewriters and sewing machines.

Furthermore, it reported the sudden increase in suppliers and producers of calculators created a buyer's market such that prices would drop to dramatically low levels and remain low in the future. Lastly, it was also predicted that "every student will use one [pocket calculator] in place of a slide rule". In hindsight, this prognosis obviously reality and it would be unimaginable today to teach high school maths without calculators.

In June 1974, the *New Scientist* once again reported that calculator prices were continuing to plummet. This resulted in a shrinking of the total value of the market despite the fifteen million calculators sold in 1973. Similarly, Japan's share of the world market dropped from 80% in 1971 to 40% in 1973. This and the following statements can be found in New Scientist (1974). Furthermore, within these two years, the prices of calculators produced in Japan decreased by more than 70% as the average price was $275 in early 1971 and only $60 in 1973. The New Scientist also states that between one and five million units in 1970 were worth more than in 1974. Thus, electronic calculator companies tried

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to position themselves in the top market segment by distinguishing themselves on functionality instead of low price. One example of such a company is *Hewlett-Packard* with their powerful scientific calculators.

In contrast, the production of pocket calculators began quite late in the GDR as the development of their state models only began in 1975. However, the GDR's first success in catching up with the Western technology was much earlier as they copied a Texas Instruments integrated circuit in 1972 as stated in Berghoff and Balbier (2014). The first GDR electronic calculator was introduced in around 1973, named *Minirex 73*. Its size resembled that of a desk calculator.

The very first, more or less pocket sized, calculator line was named *konkret* and suceeded the previous minirex table calculator series. The konkret series still used an LED display instead of an energy saving LCD display which was already widely adapted in Western products. Furthermore, the functionalities were quite limited as the simple computation, for example of a square root was not possible with the *konkret100* entry level machine.

A dedicated model to be used for educational purposes in East German schools


OFF ON
DEG RAD GRD
arcsin arccos arctan
F sin cos tan
e^x 10^x
ln lg MR X·M M+
% √ x^2 y^x 1/x
EEX 7 8 9 −
π 4 5 6 ÷
+/− 1 2 3 ×
CE·C 0 , = +
SCHULRECHNER SR1
UWE ZIEGENHAGEN

was produced under the name *Schulrechner SR1* in 1988 by the *VEB Röhrenwerk Mühlhausen*. It was available for sale for over 100 DDR marks and was able to compute multiplication and division before addition and subtraction.

New Scientist (1973) indicated that calculating techniques in the Soviet Union were even less advanced than in the GDR. It is reported that there were only 45,000 electronic calculators in the Soviet Union in 1971. Also, the majority of calculator imports, mechanical ones included, seem to have come from the GDR. This might be another indication for the advances of the GDR in comparison to the Soviet Union with regards to calculators. However, this article might be part of Western propaganda as the Soviet Union demonstrated their first electronic calculator *VEGA* in in 1962, only one year after the presentation of the Western *Anita*.

Yet another milestone was achieved by the Western company *Tandy*, who produced the first calculator-sized handheld programmable computer, commonly known as a pocket computer in 1980. While the name suggests a very small portable computer comparable to the *Palm PDA*, pocket computers from the 1980s are more similar to programmable calculators. However, they came


SHARP
POCKET COMPUTER PC-1401
MEMORY SAFE GUARD / AUTO POWER OFF
POWER
ON
OFF
CAL RUN PRO BASIC
STAT PRINT
MODE
CAL
BASIC
BRK
DEF
SHIFT
DEL
INS
INPUT IF THEN GOTO FOR TO STEP NEXT LIST RUN
PRINT USING GOSUB RETURN DIM END CSAVE CLOAD
SPC
P↔NP
ENTER
hyp sin cos tan F↔E C·CE
→HEX →DEG ln log 1/x
EXP
STAT
DATA CD
RM
M+

equipped with a full alphanumeric keyboard to allow for decent programming of their own functions. Pocket computers manufactured by many other companies such as *Casio*, *Sharp* and *Seiko* followed.

It is worth mentioning that the *Sharp PC-1401*, introduced in 1983, was the first pocket computer to combine the advantages of a scientific calculator and *BASIC* capabilities. It could be used like any other calculator simply by setting it to a *calculator mode*. This mode even included a set of statistical functions, making it especially useful for data analysis. As additional programming might be needed, it could also be switched to the *programming mode* to implement its own functions. Additional buttons could be used as shortcut keys to run *BASIC* functions.

A full comparison of pocket computers and programmable calculators can be found in Popular Mechanics (1982) where it is also suggested that pocket computers were usually used with a variety of peripheral objects and accessories such as a cassette or a disk storage system, a simple printer and possible connection to an external monitor. More advanced models were even able to draw symbols and bar charts, making it, back then, a powerful tool for applied

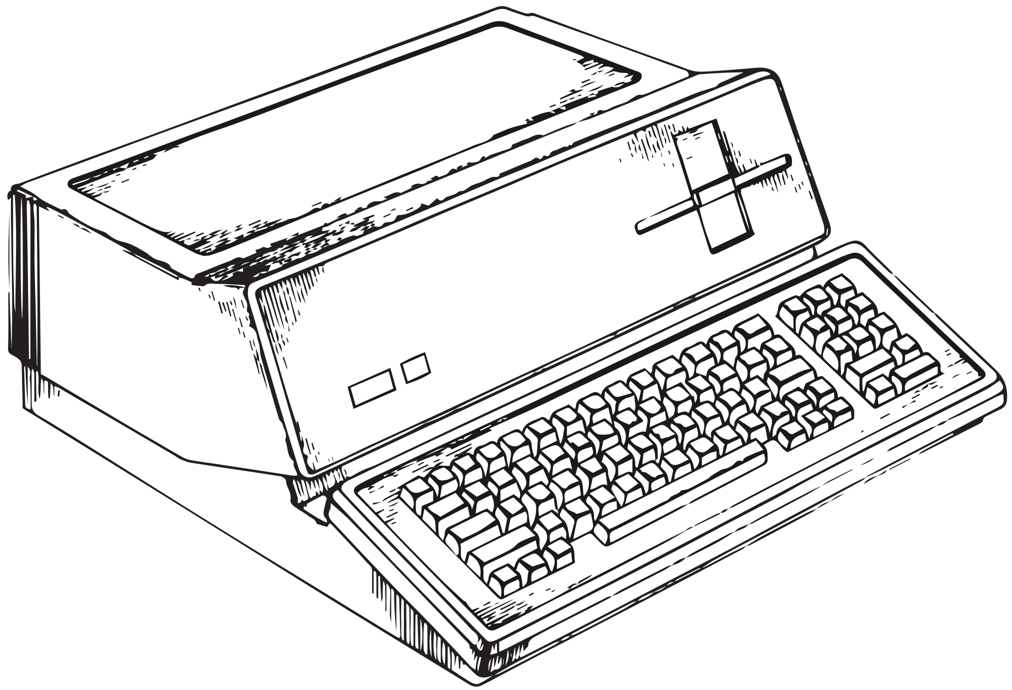

SHARP
POCKET COMPUTER PC-1270
MEMORY SAFE GUARD / AUTO POWER OFF
POWER OFF ON
ON
CA
C·CE
MEMORY
%
R·CM
M−
M+
7 8 9 ÷
4 5 6 ×
1 2 3 −
0 • = +
IN
OUT
YES
NO
ENTER
FOLIEN
FILM
MONITOR
FILM
KINE
FILM
NEUER
KEIL
ANZEIGE
STUFEN
DATEN
EINGABE
WERTE

mathematicians and statisticians. The main programming language for pocket computers was usually BASIC but some models also allowed for programming in Assembly, Lisp and Fortran.

Other models like the *PC-1270* by *Sharp* could be highly individualised by programming the different buttons. On the other hand, this model did not have a full keyboard meaning that dedicated programs had to be either developed on a calculator with a full keyboard or on a computer. The model shown was obviously used to control a slide projector.

In 1981 the German electronic music band Kraftwerk released their album "Computer World" containing the song "Pocket Calculator". Notably, the Casio fx-501P programmable pocket calculator had been used among others as a synthesizer on this album. Another customised Casio model was available as Kraftwerk merchandise, available with song sheets that clarified the key sequence for the different Kraftwerk songs.

Personal Computers



In the 1940s, it probably seemed unimaginable that one day computers would be part of almost everybody's day-to-day life. While the *ENIAC*, launched in 1946, is commonly referred to as the world's first computer, this statement is not completely accurate as hypothesised by Reilly (2003). Accordingly, it would be more correctly described as the "world's first automatic, general-purpose, electronic, decimal, digital computer". Previous computers like the British *Colossus* from 1943 were often special-purpose machines that were used to decypher codes during World War II.

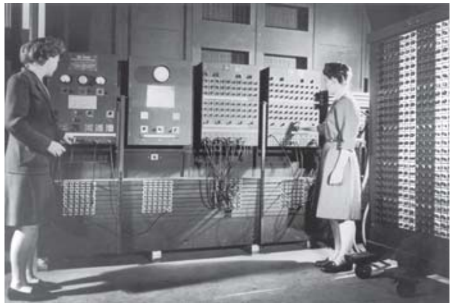


Figure 8: ENIAC

The acronym *ENIAC* originates from *Electronic Numerical Integrator And Computer* and was built at the University of Pennsylvania and funded by the United States Army. Originally, it was designed to operate with 5,000 vacuum tubes but ended up having more than 15,000 tubes by the end of its operation in 1955 while weighing more than 27 tons and occupying around 167 m^2 of space. Astonishingly, *ENIAC* was programmed by a team of six women, making them the world's first computer programmers as stated by McCartney (1999). Accordingly, Figure 8 shows *Elisabeth Jennings* and *Frances Bilas* programming the *ENIAC*. While this seems to be in stark contrast to today's shortage of women in technology, one has also to note that back then, they were regarded as clerks.

Early electronic computers were costly and huge in size but the main working mechanism remains the same today. Information is converted into ones and zeroes, namely a binary system, and then "represented" by the computer hardware. The basic unit in computing that holds each part of this information is called a bit. To be able to input new data and perform operations on this data, each bit must be physically implemented with a two-state device that is able to switch between the values one and zero.

In the 1950s each bit was physically represented by a single vacuum tube which was roughly the size of a thumb. A challenging problem was that these tubes were prone to fail regularly while thousands of tubes were needed to build a single computer, according to McCartney (1999). Locating the failed tube was time consuming and replacement was costly as the computer could only often stay operational for a few hours. Interestingly, today's common term to refer to a program error is a *bug* and originates from the vacuum tube system. Insects were often drawn to the heat and light of the tubes and sometimes caused the technical failure of the tubes.

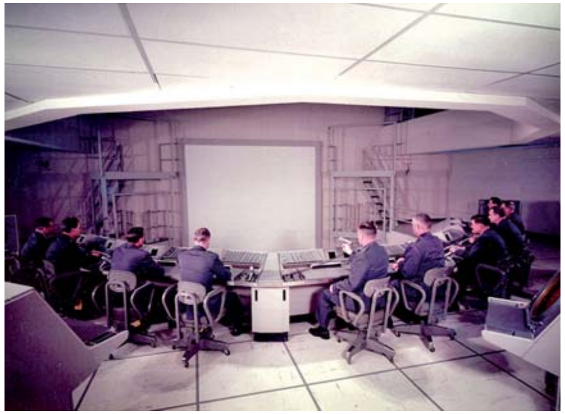


Figure 9: SAGE

The large and powerful computer *Semi-Automatic Ground Environment*, abbreviated as *SAGE*, of the U.S. Airforce had about 60,000 vacuum tubes and weighed 250 tons according to Jones (2014). Furthermore, its original software had around 500,000 statements in assembly language. By common knowledge, it is the largest computer ever built. While it was repeatedly updated, it still stayed operational until 1983 when transistor technology was already available.

Using early computers was time consuming and quite awkward. The only monitoring device was a panel of light bulbs with the state of each bulb indicating the value of a bit inside the computer. Also, these computers were programmed in, for humans, tedious *machine language*, the lowest-level programming language, with which to perform operations. This might also be the main reason why imperative programming languages such as *FORTRAN* and *LISP* were developed in the late 1950s. A more detailed overview about the historical development of programming languages is given by Deitel and Deitel (1986).

By 1959, vacuum tubes were replaced by transistors, invented by *Bell Lab* in 1948. They were faster, smaller and more reliable. Still, computers remained so expensive that until the 1980s several people had to share one machine. In the 1950s and 1960s this shortcoming was overcome on a technical level by a *batch system* which worked as follows (compare Deitel and Deitel (1986)). Each job was prepared on another medium such as punched cards or magnetic tape. The programs were then given to an operator of the computer. The operator then sorted all individual programs into batches of similar inputs and thus, the processor use was maximized. It is clear that the user who wrote the programs did not interact directly with the computer, hence, software debugging was a time-consuming process as programmers could not directly check whether a fix would work or not.

Figure 10: 1970's HP terminal

This changed during the 1970s when batch systems were replaced by *time-sharing* systems, which still relied on one computing machine but with the addition of several terminals that would be operated simultaneously. Hence, the processor's time was shared between multiple users and the response time minimised. Accordingly, users were described as being *interactive* as stated by Deitel and Deitel (1986). This time-sharing concept is still in use today and provides computing power to several people via a computer server.

Depending on the definition of a *personal computer* (PC), the first PCs were either available in the 1960s or in the late 1970s. In the 1960s, a personal computer meant that the computer is, in contrast to a mainframe, used by a single person. By this definition, the first PC was developed at the *Massachusetts Institute of Technology* and was named *Laboratory INstrument Computer* (LINC) as described by Cook (1992). It was created to aid researchers in writing code for the mainframe computers where the actual scientific computations took place.

Furthermore, these computers were not ready-to-use as modern computers but the scientific staff had to assemble them themselves. Obviously, this approach required a good understanding of the underlying hardware. Each of these LINCs cost about $32,000 as stated by Allan (2005) and hence, the PC back then was far from a home hobbyist instrument due to its price and size. The electronics cabinet was about the size of a refrigerator and a transistor system was used instead of modern microprocessors.

However, the era of the PC as a home computer had already dawned in the late 1970s and developed further throughout the 1980s. The first commercially available microprocessor was introduced under the name *Intel 4004* by *Intel Corp.* in 1971. With the rise of microprocessors, computers finally became small and inexpensive enough that hobbyists could purchase them.

The first PCs intended as home computer were sold by *MITS* under the name *Altair 8800* in 1975 and *Apple Computer, Inc.* in 1976 as kits that had to be assembled by the consumers themselves. Furthermore, companies like *Commodore International, Ltd.* started to sell ready assembled computers and tried to market the PC to the masses. Remarkably, the computer museum owns a *Commodore PET*, the first fully equipped off-the-shelf home computer.

These machines, while still bulky and slow by modern standards, already had most of the components a modern PC still has, such as a keyboard and a monitor or the ability to use a television instead of a computer monitor. However, due to the command line as a main interaction tool, the very early PCs were usually not delivered with a mouse. This changed with the introduction of *graphical user interfaces* (GUI) and some of the first computers that offered a GUI are Apple's *Lisa* in 1983 and its successor the *Macintosh*.

The PC certainly marked the beginning of a new era. While in 1977 48,000 PCs where sold according to Kanellos (2009), this number increased to 125 million

Figure 11: Apple Lisa II

PCs in 2001 and by 2002 more than half a billion were in use. Altogether, more than one billion PCs have been sold until 2002. According to Gartner, an international data corporation, more than four billion computers were sold in total by 2015 as reported by Statistic Brain (2015).

With regard to computing power, a smartphone today is much more powerful than a multimillion dollar computer in the 1960s: the guidance computer of the Apollo 11 spacecraft operated at 0.043MHz and had 64 kilobytes of memory while an iPhone 5s has a CPU that may run at 1.3 GHz and 1GB of memory.

This astonishing development of computing power can be described by *Moore's law* In 1965, the head of research and development of the *Fairchild Semiconductor company*, Gordon Moore, published his predictions about the future of the semiconductor industry in Moore (1965). Based on the observation, that in the past the number of components on dense integrated circuits had doubled every year, he expected this exponential growth to continue for at least another ten years. Gordon Moore is today also known as the the co-founder of *Intel Corporation*, one of the largest semiconductor chip producers.

Moore's quote was made popular by the US scientist and engineer Carver Mead, who coined the term "Moore's law", the law is nowadays linked to various technical developments referring to different time periods. For microprocessors, a doubling of transistors is happening approximately every 18 months, which is mainly driven by miniaturisation. While Moore's observation was based on inadvertent historic developments, it became a common target among competitors in the respective industries and therefore, it also has the reputation of rather being a self-fulfilling prophecy than a natural law. Moore's law has made pretty accurate assumptions about the evolution of the semiconductor for about 50 years.

It is, however, obvious that this trend cannot continue in perpetuity and there are numerous speculations about the end of this development. Moore himself stated in 2005, that finally the miniaturisation would be limited to the atomic level, which he predicted to happen by 2025. In contrast, the ultimate physical limitations might allow Moore's law to continue for another 250 years Lloyd (2000).

Regarding the production of microprocessors, Intel CEO *Brian Krzanich* stated, that the miniaturisation of transistors has slowed down, from a transistor size of 22 nanometers (nm) in 2012 to the current size of 14 nm in 2015, to reach a size of 10 nm by the end of 2017. Krzanich therefore has adjusted Moore's law (from now), to a period of 24 to 30 months.

Despite further technical possibilities for miniaturisation, the production of such tiny components is difficult and cost-intensive. The microprocessor industry now comes to a point, where the increase in benefit of more and smaller transistors for everyday electronics does not outweigh the increasing costs of production.

For our figures, we have obtained data regarding transistor counts by scraping it from Kanellos and Wikipedia. A scraper is an automated approach to downloading information from the internet. We have then combined both data sources and have removed duplicated transistor counts for each year. There are 172 observations between 1971 and 2016 available and thus, there are 46 years in the data set. A variable is created to account for the year of market introduction, taking values between 0 and 45.

Furthermore, define c_i as the transistor count and t_i as the year of observation of the CPU i. As an exponential decrease of the price per unit of space is suspected, we linearise the relationship by using a log transformation for the dependent variable c_i.

Thus, we assume the model

$$\log(c_i) = \alpha + \beta t_i + \varepsilon_i \tag{1}$$

holds. The results of the corresponding linear regression are shown in Table 1. HC3 standard errors are used to be consistent in case of possible heteroscedasticity. A thorough discussion of the properties of this estimator can be found in Long and Ervin (2000). As a result we can state that we expect the transistor count to rise by 35% each year. The high R^2 value of 0.94, the proportion of explained variation, and the statistical significance of the estimated parameters substantiate the findings.

Variable	Estimate	Standard Error	p-value
$\hat{\alpha}$	6.95	0.22	< 0.01
$\hat{\beta}$	0.35	< 0.01	< 0.01
R^2	0.94		

Table 1: Regression results CPU Transistor count, N = 172 CMBcpureg

Figure 18 shows the various data points as a scatter plot and the estimated regression model as a dashed line. Here, we observe that a linear model might not result in an ideal fit as the model underestimates the transistor count in the later years. Hence, a nonparametric approach or a segmented regression might be more suitable but was not performed due to the relatively small sample.

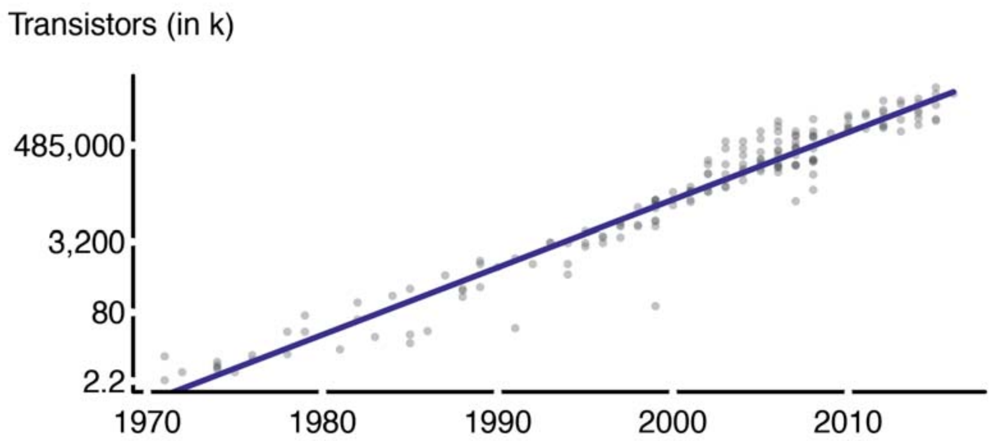


Figure 12: Estimated regression line (blue) and historical observations (scatter)
CMBcpuregp


commodore
PET
2001 Series
personal
computer

Commodore

1977

Specifications

1 MHz

4 kB

14 kB ROM

Commodore BASIC

PET

The acronym PET stands for Personal Electronic Transactor. It is the first fully equipped home computer that was shipped fully assembled. Furthermore, it set standards for other 8 bit systems developed later. On this computer, Basic and Assembly were used as main programming languages. Data could be read and written via data cassette. The keyboard was nicknamed “chiclet keyboard” due to its similarities to chewing gum. Due to constant customer complaints, this keyboard was later replaced with a larger, higher quality one.


VICTOR
CAPS LOCK

Victor Tech. Inc.

1981

Specifications

4 Mhz

128 kB

10 MB

MS-DOS

Victor 9000

Also called Sirius I in Europe, the Victor 9000 was designed by Chuck Peddle who also designed the Commodore Pet. It was marketed as a business machine and had the largest software library of its time, if compared to similar machines. However, the Victor 9000 could not run IBM software which led to its parent company's bankruptcy in 1984. The showcased model was used to implement HOMEX and expert systems. The software was written in Turbo Pascal and can fit onto just 64 KB of storage space. We thank Prof. Erich Neuwirth for the donation.


robotron
A 5120

VEB BuchungsMW

1982

Specifications

2.5 MHz

64 kB

CP/M compatible

Robotron A 5120

The desktop the Robotron A 5120 was launched in 1982. It represented the first version of the office computer in the GDR. For its time Robot A 5120 had rather good characteristics, such as: flexible configuration options, compact construction and easy serviceability. In the 1980s the Robotron A 5120 was mostly used by companies and scientific institutions, partly because its price ranged from 60,000 to 80,000 DDM which was pretty high.


IBM
IBM

IBM

1982

Specifications

4.77 MHz

512 kB

MS-DOS

5150

The IBM 5150 is IBM's first of many PCs and was firstly introduced on 12 August 1981. It set the standard for all computers produced by IBM and all of today's IBM computers are theoretically backwards compatible. Initially it had two 5 1/4" disk drives but no hard drive disk. The model owned by the CM was bought for about 10,000 DM in 1985 by the Institute of Finance and Banking of Augsburg University. As the institute's first computer, it was shared by the research assistants for scientific purposes. We thank Prof. Richard Stehle for the donation.


sinclair
ZX Spectrum
BLUE EDIT 1 ! DEF FN
RED CAPS LOCK 2 @ FN
MAGENTA TRUE VIDEO 3 # LINE
GREEN INV. VIDEO 4 $ OPEN #
CYAN 5 % CLOSE #
YELLOW 6 & MOVE
WHITE 7 ' ERASE
8 (POINT
GRAPHICS 9) CAT
BLACK DELETE 0 FORMAT
SIN Q PLOT ASN
COS W DRAW ACS
TAN E REM ATN
INT R RUN VERIFY
RND T RAND MERGE
STR $ Y AND RETURN [
CHR $ U OR IF]
CODE I AT INPUT IN
PEEK O POKE OUT
TAB P PRINT ©
READ A STOP NEW
RESTORE S NOT SAVE
DATA D STEP DIM
SGN F TO FOR
ABS G THEN GOTO
SQR H GOSUB CIRCLE
VAL J LOAD VAL $
LEN K LIST SCREEN $
USR L LET ATTR
ENTER
CAPS SHIFT
LN Z COPY BEEP
EXP X £ CLEAR INK
L PRINT C ? CONT PAPER
L LIST V / CLS FLASH
BIN B * BORDER BRIGHT
IN KEY $ N NEXT OVER
PI M PAUSE INVERSE
SYMBOL SHIFT
BREAK SPACE

Sinclair

1982

Specifications

3.5 MHz

16 kB

Sinclair BASIC

ZX Spectrum

The ZX Spectrum is a UK-based 8 bit home computer with a colour display. The producer marketed it to a mainstream customer base and it soon became a rival to the Commodore 64. Each key of the rubber keyboard can perform more than one function. In total, five million units were sold worldwide and it has remained so popular that there are software releases even today. The showcased computer was privately owned and originally used to learn the programming language BASIC from. We thank K. Lanyi Scott for the donation.


People
MEMORY SIZE = 80000H BYTES
BOOT DRIVE NAME ?
OLYMPIA
People

Olympia Werke AG

1983

Specifications

2 MHz

64 kB

People

This computer was manufactured in Japan and its parent company was an important German producer of typewriters which attempted to also produce electronical calculators and desktop computers. Their products failed because they lacked technological innovations. Thus, the company struggled after the decline of the demand for typewriters and the original company went out of business. The showcased desktop was mainly used for typing, working with electronic tables and playing games. We thank Burkhard Beletzki for the donation.


apple
//e
IN USE
disk II
IN USE
disk II

Apple

1983

Specifications

1 MHz

128 kB

ProDOS 8

IIe

The e suffix acknowledges the fact that several additional features were added to this third model of the Apple II series. These enhancements include a full ASCII character set and the capability to input and display lower-case characters. The two floppy disk drives hold both the OS and the individual user's data. The showcased computer was formerly used for mathematical and statistical education at Humboldt Gymnasium Berlin. We thank Stefan Heck for this donation.


PHILIPS
VG-8020
HOME
COMPUTER
80K RAM
32K ROM
EXPANDABLE SYSTEM
MSX
POWER
CAPS

Philips

1984

Specifications

2.58 Mhz

64 kB

32 kB

VG 8020

This 8-bit computer incorporates MSX architecture, the first industry standard for home computers that allows for platform independent software development. While Microsoft announced MSX as an abbreviation for MicroSoft eXtended, the intellectual inventor, Kazuhiko Nishi, pointed out that this was not originally the intention. The VG 8020 was not very successful due to competing machines built by Commodore, Atari and Sinclair and the overcrowded 8-bit computer market. We thank Dr. Sebastion Winsel for the donation.


JUNOST-402B
KC 85/2 COLOR
BASIS DEVICE
EXPANDER RAM
BASIC
POWER
ROM
RAM
IRM
KC 85/2 KEYBOARD

VEB Mikroelektronik

Specifications

1.75 MHz

32 kB

16 kB

HC-CAOS year

KC85/2

The Kleincomputer was built in the GDR and was aimed at individual users as its main customers. However, private individuals seldomly had a chance to buy it due to enormous demand by educational, industrial and military establishments. A standard television set acted as a monitor and only pseudographics were provided to emulate raster graphics with special character sets. The modular construction allowed for numerous additional hardware such as a printer or extra RAM.


****
* C.A.S.E. *
* Computer *
* Museum *
****
Ready
Schneider
Green Monitor »GT 65«

Schneider

1985

Specifications

4 MHz

128 kB

CP/M

CPC

The manufacturing company Schneider was originally known for audio products and entered the computer market in a joint partnership with Armstrad in 1984. Their cooperation ended in 1988 when Schneider was not willing to market Armstrad's AT-compatible computer line and the company went bankrupt in 2002. The CPC is one of the the last computers that relied heavily on the Armstrad designs. The appearance resembles the Amiga due to the keyboard being integrated into the PC case.


robotron 1715

VEB BuchungsMW

1985

Specifications

2.5 MHz

64 kB

CP/A compatible

Robotron 1715

In the 1980s, the Robotron 1715 was the standard computer in the GDR but was also widely used in Russia and other East European countries. This was more due to the fact that this computer was quite cheap but had limited capabilities. It could not be acquired at outlets and was only available to state enterprises and government agencies. Additionally, owing to its low performance, the PC 1715 had several design flaws: The supply power switch was very unreliable, the monitor cable was too short and the keyboard often got stuck.


commodore 16
POWER

Commodore

1986

Specifications

0.89 MHz

16 kB

32 kB

Commodore BASIC

C16

This entry-level computer was introduced to the market to provide a counterpart to cheap models by Commodore's competitors. The C64 software was not compatible with the C16. The C16 was, in contrast to the C64, the best-selling single computer model of all time, a commercial flop. It was discontinued in the U.S. within one year. This exact C16 model was actually acquired as part of a packet with a programming course, which was offered at several West German department stores in 1986.

Homebuild

1987

ZX Spectrum Clone

This clone of a commercial product was assembled in the GDR by nine electronic specialists. They used only parts available in the GDR, ČSSR and USSR. Several simpler chips were used instead of one processor.

In the GDR and other socialist countries, industrially manufactured computers were only available to public bodies and not private citizens. We thank Michael Rumpf, one of its creators, for the donation.


IBM

IBM

1987

Specifications

16 MHz

8MB

40MB

IBM PC-DOS

PS/2

IBM introduced the Personal System 2 to regain the lead in the PC market in 1987. This attempt was unsuccessful due to the PS/2's high price and in spite of IBM's extensive marketing efforts. The slogan "How ya' gonna do it? PS/2 it! The solution is IBM" is part of the largest marketing failures in company history. At that time, IBM was still the largest single manufacturer of PCs but later lost this status to Compaq. Nevertheless, the PS/2 set standards for computers produced many years later.

Ablage Bearbeiten
Album
100%
75%
50%
25%
% Gewinn
A B C D E F G H
Produkt
5/7
PICT
Macintosh Classic

Apple Computers

1990

Specifications

8 MHz

1 MB

40 MB

Mac OS 7

Macintosh Classic

Unlike Apple's previous strategy of aiming at the high-end market segment, this all-in-one Mac can be seen as a low cost revival of its predecessor, the SE/30. The lower price tag was made possible by out-dated hardware, making it the first Macintosh to be sold for less than $1,000. The, back then, new brightness control panel allowed users to manage the display's brightness in a much more convenient software based way, a feature still present in modern Apple computers.


AMIGA
Commodore
A-500 Plus

Commodore

1991

Specifications

7.16 MHz

4 MB

80 MB

Amiga OS

Amiga 500 Plus

The A500+ is the enhanced version of Commodore's first affordable and hence privately used computer, the A500. This upgrade led to several incompatibilities with already existing software that had been developed for its predecessor. Together with the A500, the A500+ is the best selling Amiga of all time. This was probably due to the fact that it was a low budget computer and was widely available. It also had great graphic capabilities compared to other PCs at the time, which led to many games being developed for it.


Sun
SPARCstation 10

Sun Microsystems

1992

Specifications

166 MHz

512 MB

Sun OS / Solaris

SPARCstation 10

Sun's SPARCstations were a line of work-stations produced for the high end computer market. The line of workstations was very popular because of the performance and stability the SPARC architecture could provide compared to other competing architectures such as Intel's x86. Many SPARCStations were used as servers because of these characteristics. A similar SPARCstation acted as a web and file server at the Chair of Statistics at Humboldt-Universität zu Berlin. Because of their size and shape they were nicknamed "pizza box".


INDY
SiliconGraphics

Silicon Graphics

1993

Specifications

100 MHz

32 MB

IRIX

Indy

Indy was marketed as a low budget machine for 2D and 3D graphics editing and desktop editing. Similarly to today, this market segment was dominated by Apple however SG experienced a massive growth between 1984 and 1997. It was the first computer with a build-in digital video camera and had an ISDN adapter. The attempt in 1999 to widen the product range to more than graphics computers failed, resulting in the company being delisted from the NYSE in 2005 and ultimate to bankruptcy in December 2008.

Rechner: Mars
IP 100.229
CPU Ultra2
OS SunOS 5.5.1
Sun
intel outside
ULTRA 2
ULTRASPARC

Sun Microsystems

1995

Specifications

200 MHz

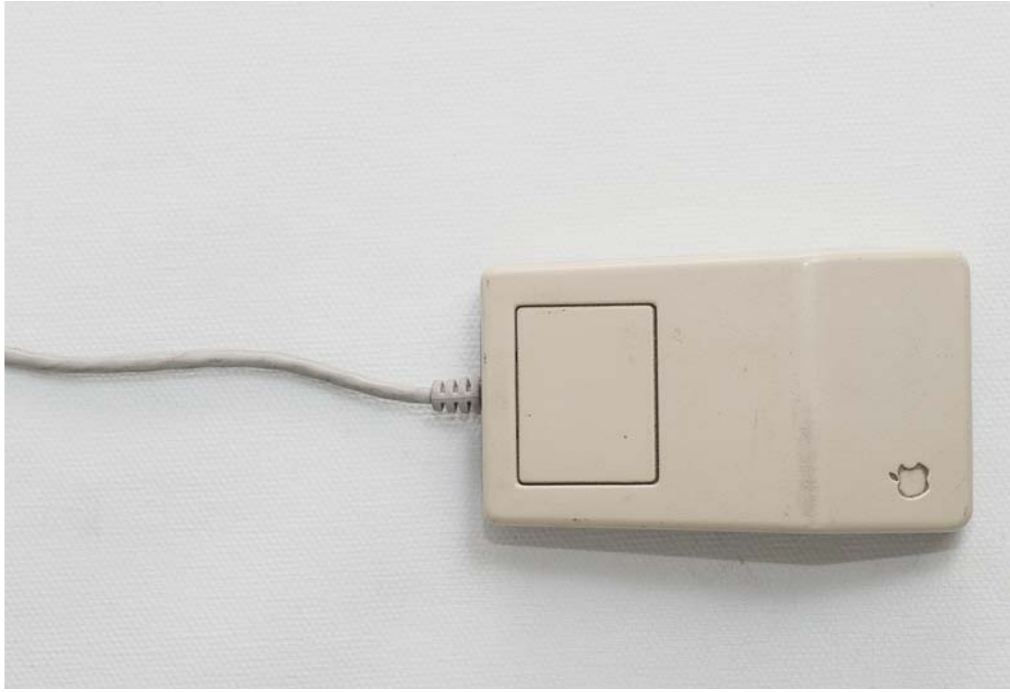
128 MB

Sun OS / Solaris

Ultra 2

The Ultra series succeeded Sun's Super-SPARC workstation. A main improvement of the new UltraSPARC architecture was the 64 bit processor raising the theoretical amount of addressable memory to 2^{64} bytes, a development Intel's desktop processors only made almost ten years later. Earlier Ultra models in particular featuring high end SCSI and SBus interfaces were widely adopted and remained popular for years. A dual core Ultra 2 was one of the first servers employed by Google at Stanford University. The model depicted called "Mars" was used at the Chair of Statistics at Humboldt-Universität zu Berlin as a web server.


PowerPC
Power Macintosh
8200/120



Apple Computers

1996

Specifications

132 MHz

16 MB

1 GB

Mac OS 8

Power Macintosh 8200/120

Power stands for the use of PowerPC microprocessors which were developed by an Apple–IBM–Motorola alliance. As an extended version of the Power Macintosh 7200 it is still a low end computer for graphic and video editing. In comparison to the 7200, it was only available with a PC tower case and was only distributed in Europe. The slogan for all Power Mac TV commercials was "The Future Is Better Than You Expected".


iMac

Apple Computers

1998

Specifications

400 MHz

348 MB

Mac OS 9 / Mac OS X

iMac G3

Marketed as the computer for the new millennium, the “i“ originally stood for “internet“. While the internet is taken-for-granted today, the “i“ still remains in the names of Apple’s current product lines such as the iPhone. The futuristic, translucent and indigo blue design led to numerous appearances by Apple products in pop culture and helped Apple to reclaim its leader status in the computer market. The showcased computer was used for typical office work at the Berlin Institute of Technology. We thank Dr. Martin Wersing for the donation.

Apple Computers

1999

Specifications

350 MHz

256 MB

40 GB

Mac OS X

Power Macintosh G3

This “Blue and White” Power Mac presented Apple’s millennial design paradigm while still using the same CPU’s as in its predecessor. The mechanism was easily accessible due to a novel folding door that swung downwards. The case design itself was codenamed “El-Capitan”. Furthermore, several ports were removed and other ports were added, such as a FireWire and USB ports. Due to the outdated CPU, it was discontinued in the same year as it was released.

Apple Computers

1999

Specifications

400 MHz

512 MB

Mac OS X

Power Macintosh G4

While the design is similar to the "Blue and White" G3, albeit with a different colour scheme, this Power Mac featured several improvements regarding its technical specifications. Apple went even so far as to advertise it as the first personal supercomputer. The standard model came with DVD-ROMs and some versions also featured Zip drives as standard. Some G4s had such noisy fans that they were nicknamed "Wind tunnel G4".


Safari Ablage Bearbeiten Darstellung Verlauf Lesezeichen Fenster Hilfe
Fr 19:42
Quantnet :: Show
http://quantlet.de/index.php?p=show&id=2273
Google
Source Code:
Download as File
bs_call <- function(S, K, r, tau, sigma) {
# Black-Scholes formula for European call price with b = r
# (costs of carry = risk free interest rate -> the underlying pays no continuous dividend)
d1 = (log(S/K) + (r + (sigma^2/2)) * tau) / (sigma * sqrt(tau))
d2 = d1 - (sigma * sqrt(tau))
C = S * pnorm(d1) - K * exp(-r*tau) * pnorm(d2)
return(C)
}
# Input
S = 100 # stock price
K = 100 # strike price
r = 0.1 # risk free interest rate
tau = 0.6 # time to maturity (blue line)
tau2 = 0.003 # time to maturity (red dotted line)
sigma = 0.15 # volatility of first plot
sigma2 = 0.3 # volatility of second plot
lb = 0 # lower limit of x axis
ub = 170 # upper limit of x axis
# Calculate Black Scholes prices as a function of S with two different volatilities and time to matu
call1 = bs_call(c(lb:ub), K, r, tau, sigma)
call1_2 = bs_call(c(lb:ub), K, r, tau2, sigma)
iMac

Apple Computers

2002

Specifications

333 MHz

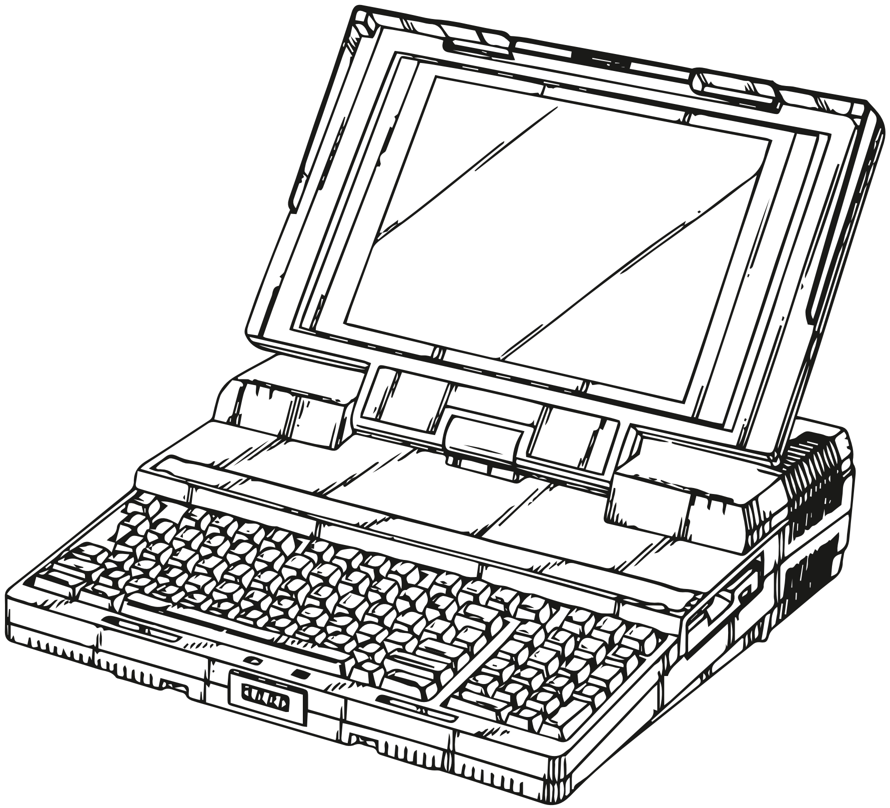
256 MB

Mac OS X

iMac G4

This patented futuristic design featured an LCD display which was mounted on an adjustable arm above the main computer. During its launch, Steve Jobs stated: “The CRT is officially dead”. It was the first completely redesigned iMac and was also known as the “New iMac” or “sunflower”. It was praised by the press due to the innovative design and new technology, however, it was discontinued less than three years after initial release.

Portable Computers



At the time when computers still filled whole buildings it might have seemed like a distant futuristic world that one day a whole computer could be carried around to use it "on the go". Thus, the definition of *portable* has changed over time as it once referred to a computer that was small enough to be carried on a ship or a truck in the 1950s. Of course this changed and at the beginning of the 1980s, the first truly portable PCs were developed. The early portables where chunky, had a tiny display and they were heavy, often weighing more than nine kg.

In the late 1980s, laptops began to resemble today's models while still taking up much more space for the electronics. Today, this bulkiness has vanished as demonstrated by Steve Jobs when he unveiled the MacBook Air in 2008 by pulling it out of an envelope. Also, current capabilities of portable machines has become so advanced that even computationally intense methods such as *bootstrapping* and *clustering* are possible on these devices.


LC80
VOR FEUCHTIGKEIT SCHÜTZEN!
KEEP DRY!
CRAINT L'HUMIDITÉ!
PRESERVESE DE HUMEDAD!
RFT veb mikroelektronik
›karl marx‹ e furt
G-5403.500 MADE IN GDR
ELN 138 21 710
IP00 ≤3...12V ≤0,6A DC ≤1,0A AC
FABR.Nr. 04317

VEB Mikroelektronik

1982

LC80 Lerncomputer

This single-board computer was the commercially available computer manufactured in the GDR. “Lerncomputer” means that its main purpose was to teach people how to program and was not meant for home use. The choice of a visible circuit over a closed casing allowed the single components to be seen in order to learn about the elementary basics of digital computing. A calculator style numeric keyboard was used as an input device to enter hexadecimal machine code.

IBM

1985

Specifications

4.77 MHz

256KB

IBM PC-DOS

13.5 kg

Portable 5155

This early portable computer weighed an incredible 13.6 kg and thus, had a handle so that it could even be carried around. It is IBM's response to a very successful portable machine by Compaq and even has a lower price tag. Similarly to other early computers for the mass market, it had no hard drive but two floppy disk drives. Notably, there were several problem-solver libraries available for this machine with routines for math, statistics and finance.


supertwist LCD
AMSTRAD
PPC512

Armstrad

1988

Specifications

8 MHz

512 KB

MS-DOS

6 kg

PPC512

This computer was the cheapest portable at the time of its introduction to the market. It is IBM PC compatible and could have up to two floppy disk drives. A vast number of power sources are supported such as batteries, an adapter and even a car cigarette lighter. While being marketed as a portable computer, the PPC512 still weighed 5.4 kilogram without batteries. Customers repeatedly complained about the small and quite poor quality LCD display.


16 BIT PERSONAL COMPUTER
C:UNNAMED.WKS
A3: 7
Tue 01 Jan 80 00:02
INS
Portfolio
ATARI

Atari

1989

Specifications

4.9152 MHz

128-636KB

Portfolio DOS 2.11

0.5 kg

Portfolio

The Portfolio was the world's first palmtop computer and was originally developed by DIP Research Ltd. The Portfolio was IBM-PC compatible which made it quite universal and while featuring its own operating system called DIP DOS, it was mostly compatible with MS-DOS 2.11. It was presented by the Atari Company as being the size of a VHS cassette and with the weight of just few hundred grams. Due to the external software it could be used for programming, playing games and more complex calculations, such as taxes.


TRIUMPH-ADLER
WALKSTATION

Triumph-Adler

1991

Specifications

20 MHz

2 MB

N/A

3.5 kg

Walkstation 386 SX

The manufacturer Triumph-Adler originally built typewriters but was then bought by the Italian company Olivetti. Hence, the Walkstation's design and features were heavily influenced by the "Olivetti L1 D33". The initial price of the first Walkstation 386 SX laptop was around DM 3,500. Notable is also the blue coloured keyboard characters. Furthermore, the touchpad is not below the keyboard but above it.


PSION
SERIE 3
System
Daten
Word
Agenda
Uhr
Welt
Rechner
Programm
16 bit CPU
256K RAM
MULTI-
TASKING
BETRIEBS-
SYSTEM
Esc
Strg
Menü
Caps Lock
Hilfe
Entf
Enter
OPL

PSION

1991

Specifications

4.7 MHz

128/256 MB

EPOC16

0.265 kg

Series 3

Psion is an acronym for "Potter Scientific Instruments Or Nothing" and refers to the company's founder, the British university professor Sir David Potter. The Series 3 was one of the first useful PDAs available to the mass market. Its battery life of up to 35 hours is regarded as a very positive feature and the Series 3 became so popular that 1.5 million of them were produced.


intel inside

Clevo

1991

Kapok/Clevo

The Taiwanese producer "Clevo" was founded in 1983 and began making notebook PCs in 1987. Clevo has always mainly acted as a producer for original equipment and design manufacturers but also produces models for end-consumers under its own brand. The company itself mainly deals with buyers whose orders are too small for large manufacturers. Furthermore, the company is ranked currently as the fourth Taiwanese exporter.


Newton
Kartei
Termine
Extras
Storno
Suchen
Assist.
MessagePad

Apple

1993

Specifications

20 MHz

1/2 MB

NewtonOS 1.3/2.0

0.45 kg

Newton

This personal digital assistant was the first PDA to feature handwriting recognition. It was delivered preloaded with a variety of software to aid personal data organisation and management. In comparison with its competitors, it was a very innovative piece of technology at its debut but its high price prevented it from becoming a bestseller. While it was popular in certain fields such as medicine, the competing Palm Pilot immediately secured a larger portion of the market share upon its arrival. Not surprisingly, the Newton line was discontinued in 1998.

Highscreen

1993

Specifications

66/100 MHz

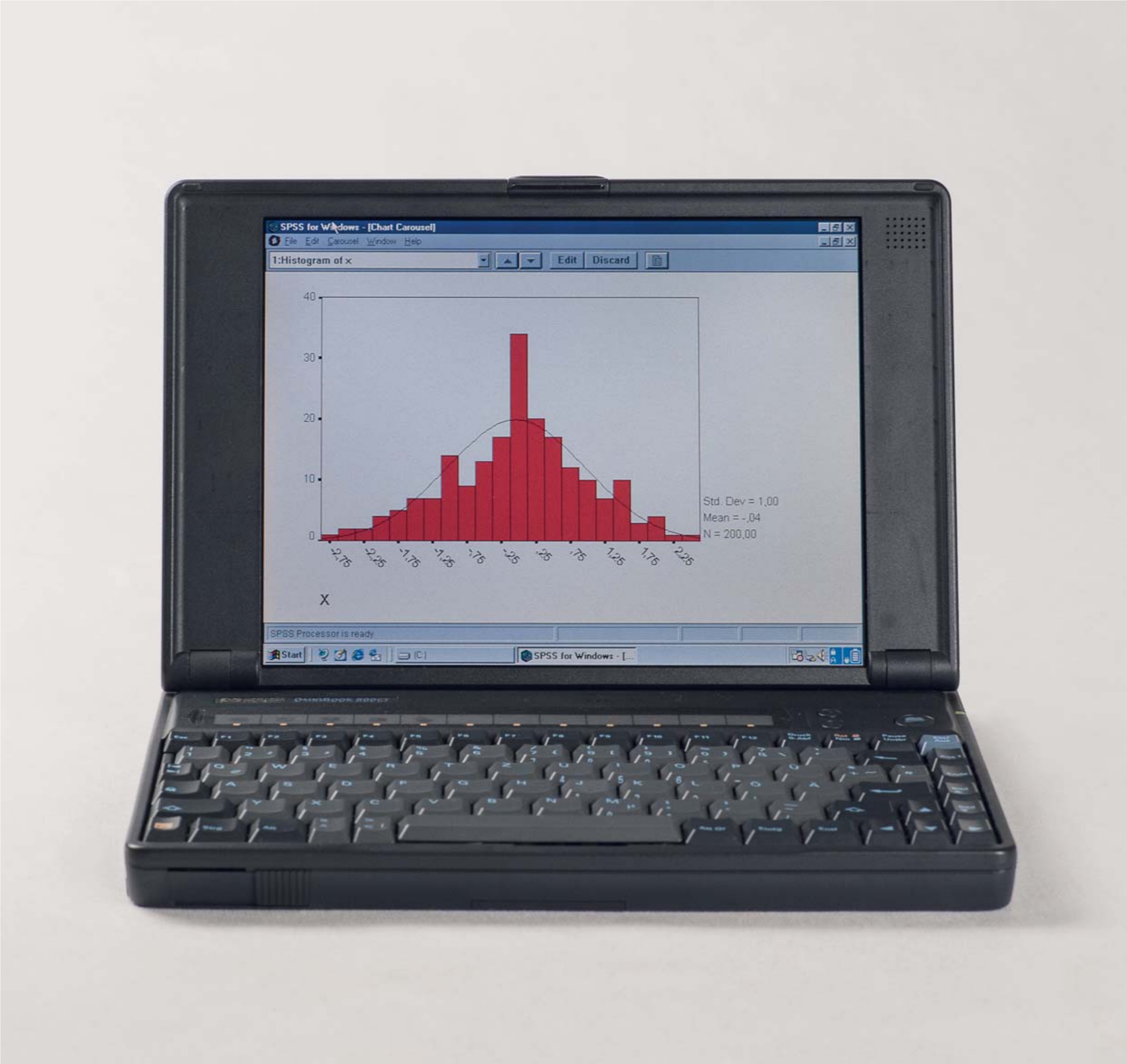
4-16 MB

MS-DOS

2.9 kg

Colani Blue Note

This computer was manufactured by "High Screen", a brand owned by the German PC distribution company "Vobis". This brand name should not be confused with the Russian company that has produced smartphones since 2009. It was designed by Luigi Colani who is mainly known for designing automobiles and planes. The deep blue colour is certainly attention-grabbing. We thank Jochen Kletzin for this contribution.


SPSS for Windows - [Chart Carousel]
File Edit Carousel Window Help
1:Histogram of x
Edit Discard
40
30
20
10
0
-2,75 -2,25 -1,75 -1,25 -,75 -,25 ,25 ,75 1,25 1,75 2,25
X
Std. Dev = 1,00
Mean = -,04
N = 200,00
SPSS Processor is ready
Start
SPSS for Windows - [...

Hewlett–Packard

1996

Specifications

100-133 MHz

16-80 MB

Windows 98

1.7 kg

Omnibook 800 CT

As the last sub-portable Omnibook and the first one to come with a Pentium processor, this device represented a change in production values at HP at that time. Back in 1996, it was an remarkable laptop as it only weighed 1.7 kg while still being reasonably fast. It is also surprising that this laptop did not come with a tracking ball or touchpad but it had an extendable mouse. The showcased model shows a histogram of 200 generated standard normal values in "SPSS", a software program for statistical analysis.


PowerPC
File Edit Equation Graph Demo Help
6:54 PM
Graphing Calculator
Graphing Calculator 1.1
y = √(x²)
Graph
Trash
Macintosh
PowerBook 1400c/133

Apple Computers

1997

Specifications

117-166 MHz

16-64MB

Mac OS 9

2.99 kg

PowerBook 1400c

This is the first Powerbook to include an internal CD-ROM drive and stackable RAM modules. The switchable "BookCover" laptop skins can be seen as the start of the trend to individualise computers. For the item shown, the grey and clear covers are included.

The PowerBook 180 was available in a vast number of different configurations and was Apple's entry-level notebook throughout its 18 months on the market. We thank Ms. Küttner-Lipinski for the donation of this laptop.


Generalized Linear Models in XploRe - Microsoft Internet Explorer
XploRe
GLM Tutorial
1 Short Theory
2 Data
3 Macros
3.1 doglm
3.2 glmest
4 Weights & Constraints
5 Options
6 Statistics
7 Output
8 Model Selection
9 Odds & Ends
Generalized Linear Models
by Marlene Müller
June 23 - 1998
GLM fit, 'bilo', n=23
Estimates (b, s.e., t-value)
b[1] 1.94469 0.3413 5.70
b[2] 1.12999 0.257 4.40
b[3] -0.762634 0.2112 -3.61
b[4] -0.847275 0.3222 -2.63
b[5] 0.227111 0.2501 0.91
b[6] -0.736812 0.2989 -2.46
* constant variable: b[1]
Start
XploRe
Generalized Linear M...
Panasonic CF-41
intel inside pentium
CDJET3

Matsushita Electric

1997

Specifications

75-120 MHz

8-16 MB

Windows 98

4 kg

Panasonic CF-41

This high-end Panasonic was available for a starting price of $8,700 and hence, it was not aimed at the typical home user. On the other hand, it had several attractive features such as onboard sound and a CD-ROM drive. Back in 1987, a drive was a luxury even on a desktop computer. Aside from technical features, the CF-41 was quite chunky, even with the small 10.4 inch screen. Furthermore, it was not as robust as one might expect due to the rather unprotected drive.

Siemens

1998

Specifications

166/200/233MHz

128-192 MB

Windows 95

3.5 kg

Scenic Mobile 710

At the end of the 1990s Siemens Nixdorf's Scenic Mobile 710 could be defined as not only unusually fast, but also as an unusually designed well-built laptop. With heavyweight build quality and a high price tag, the 710 was designed as a corporate notebook. In speed terms Mobile 710 turned in a benchmark performance. The laptop was bought in 2004 by the system administrator of the SFB 649 Rainer Voß for EUR 50. It was used to prepare for the certificate "Microsoft Certified Systems Engineer".


R Graphics: Device 2 (ACTIVE)
0
-20
-40
-60
-80
-100
-120
Y
0
2000
4000
6000
8000
10000
Time
02:33

IBM

2000

Specifications

1.1 GHz

4-14MB

OpenSuSE

2.4 kg

ThinkPad T21

As with all IBM laptops the ThinkPad Type 2647 T21 was renowned for its build quality; it could be dropped from one metre and only suffer a few scratches. Hence, Thinkpads were successful with engineers and in the consulting business as constant robust use did not wear the parts out as much as it would with other models. Another great feature was a laptop keyboard with the travel feel of a proper full keyboard. The long-life Li-Ion battery allowed for around three and a half hours of continuous work, which exceeded most of its rivals at the time.


PowerBook G4

Apple Computers

2001

Specifications

400-500 MHz

0.64-1GB

Mac OS X

2.5 kg

Powerbook G4

This PowerBook represents the dramatic change in Apple's design paradigm. It had a titanium case which was later switched to aluminium. The body itself is only one inch thick. The quality of its display is the downside of this model as it frequently malfunctioned. The showcased laptop was purchased in 2001 in order to test the Java interface for the XploRe Quantlet Server. It was the first Apple to be owned by the Chair of Statistics and was used in combination with the first iPod.


R File Edit Format Workspace Packages & Data Misc Window Help
Thu 1:06 AM
Macintosh HD
R Console
Quartz (2) – Active
iBook

Apple

2001

Specifications

500 MHz

128-640MB

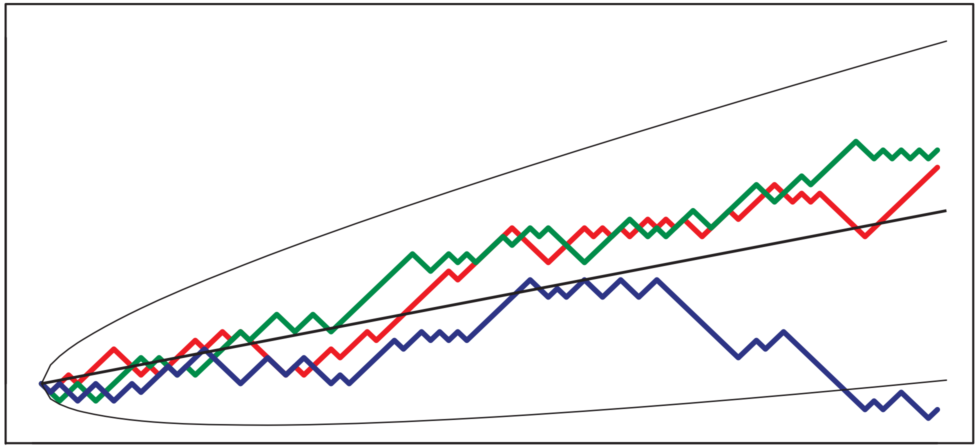
Mac OS X

3.04 kg

iBook G3

This second generation iBook, also called “snow” due to its white translucent colour, was the first computer to feature a USB connection instead of other legacy interfaces. It succeeded the previous Clamshell model, which lacked portability due to its shape, weight and size. It set many standards for later portables by Apple. The showcased model runs a copy of the statistical programming language R and more specifically, the results of a nonlinear minimisation is shown that uses a Newton-type algorithm.


Binomial processes (p=0.600)
SONY



Sony

2001

Specifications

850 MHz

128-256 MB

Windows 98

1.7 kg

Vaio

The acronym Vaio stands for “Video Audio Integrated Operation” and is a long running popular laptop series by Sony. It marks Sony’s re-entry into the global PC market and is recognisable by its iconic purple colour. However, Sony sold its PC business in 2014 to the Japanese investment company Industrial Partners. This example illustrates the quantlet SFEBinomp in the programming language XploRe which is still available for the languages R and Matlab at quantlet.de.


iBook G4

Apple

2003

Specifications

800-1000 MHz

128-640MB

Mac OS X

2.2 kg

iBook G4

The G4 has a very similar look to the former iBook G4. However, Apple updated the internal hardware extensively so that, it had, for example, a faster processor, motherboard and hard drive support. It was the last in the line of iBooks as Apple then introduced the new MacBook line to replace the iBook range.

The showcased model was used in the head office of the LvB chair of statistics. As with other computers at the LvB at that time, it carried the name "wolf" in a foreign language; more specifically "Lan" which is Chinese for wolf.


MD*Quantlets - Microsoft Internet Explorer
methods & data
QUANTLETS*
Home of the internet based
statistical methods
APSS
Electronic Books
Tutorials
Mailing List
XploRe Java Interface
XploRe Demo Version
Associated
MD*Stat - Teach
XploRe - Compute
MD*Tech - Research
more projects...
Quantlets are net based quantitative methods. Quantlets for many user groups exist. Quantlets are combined into Quantlibs. The XploRe Quantlet Server (XQS) delivers the full power of highly efficient quantitative methods to our clients. Quantlets can be accessed from many platforms from anywhere in the world. Quantlet enhanced books become more accessible to readers. Tutorials guide through complex statistical situations.
A selection of our Quantlibs:
financial applications
wavelets
micro econometrics
generalized partial linear models
teachware
nonlinear time series analysis and filtering
neural networks
generalized linear models
non- and semiparametric methods
Auto Pilot Support System (APSS)
start
hp

Hewlett–Packard

2004

Specifications

75-850 MHz

64-512MB

Windows XP Tablet PC

1.4/1.8 kg

HP Compaq TC1100

Described as one of the best tablets available at the time of its introduction, this model was attractive for both home and business users. It had one of the lightest and smallest designs during its time and featured an easily detachable keyboard. It was able to run useful tablet PC apps such as Corel Grafigo to utilise the touch screen as a graphic input device. In comparison to today's tablets it is still quite heavy as it weighs more than even the first generation iPad.


T43
IBM

IBM

2005

Specifications

1.6-2.13 GHz

0.256-2 GB

Windows XP

2.22 kg

Thinkpad T43

The T43 was the last Thinkpad to be entirely designed and manufactured by IBM before the Thinkpad line was sold to Lenovo. The red circular button called the "Trackpoint" which functioned as mouse and the simple black form are key in an easily recognisable design which had remained almost unchanged since the introduction of the first Thinkpad in 1992. IBM's notebooks were enormously popular due to their stability and ruggedness and were also used on the International Space Station.


lenovo
T60

Lenovo

2006

Specifications

1.66-2.16 GHz

0.256-4 GB

Windows 2000/XP

2.17 kg

Thinkpad T60

The T60 was one of the first models produced by Lenovo, however it still carried the IBM logo and branding. The series marked the transition from classical displays in favour of modern wide screens. Later Thinkpads manufactured by Lenovo were widely criticised for their build quality in comparison to older robuster models. This led to an unforeseen and ironic move by IBM to replace their employees' Thinkpads with Apple Macbooks.


msi
RGui (32-bit)
R Console
Click or hit ENTER for next page
smooth(presidents0, *) : 3R and default 3RS
presidents
0
20
40
60
80
1945
1955
1965
1975
Time
Drahtlose Netzwerkverbindung ist nicht verbunden

MSI

2009

Specifications

1.6 GHz

1024-2048 MB

Windows XP

1.3 kg

Wind Hybrid Luxury

This netbook is a small, lightweight and inexpensive computer. Certain features such as an optical drive or a fast processor are omitted due to weight and cost constraints. Due to their popularity, netbooks even began to take market share away from notebooks in late 2008. The showcased computer runs a script in the statistical programming language R to perform smoothing on time series data. It is customised to show Cyrillic letters using keyboard stickers.


iPad
13:01
53%
quantlet.de
Quantnet :: Start
Start
Info
Submission of new Quantlets
QuantNet 2.0 (Beta Version)
Imprint
Description
Find
Books
Multivariate Statistics
Applied Multivariate Statistical Analysis
Statistics of Financial Markets
Statistics of Financial Markets
SMS
SPM
MVA
SFE
SFS
Statistical Tools for Finance and Insurance
Applied Quantitative Finance
Basics of Modern Mathematical Statistics
STF
XFG
MSE
Projects
Keywords: Top 30
plot graphical representation
visualization
financial data visualization
simulation option
Most Recent Quantlets

Apple

2011

Specifications

1 GHz

256 MB

Apple iOS

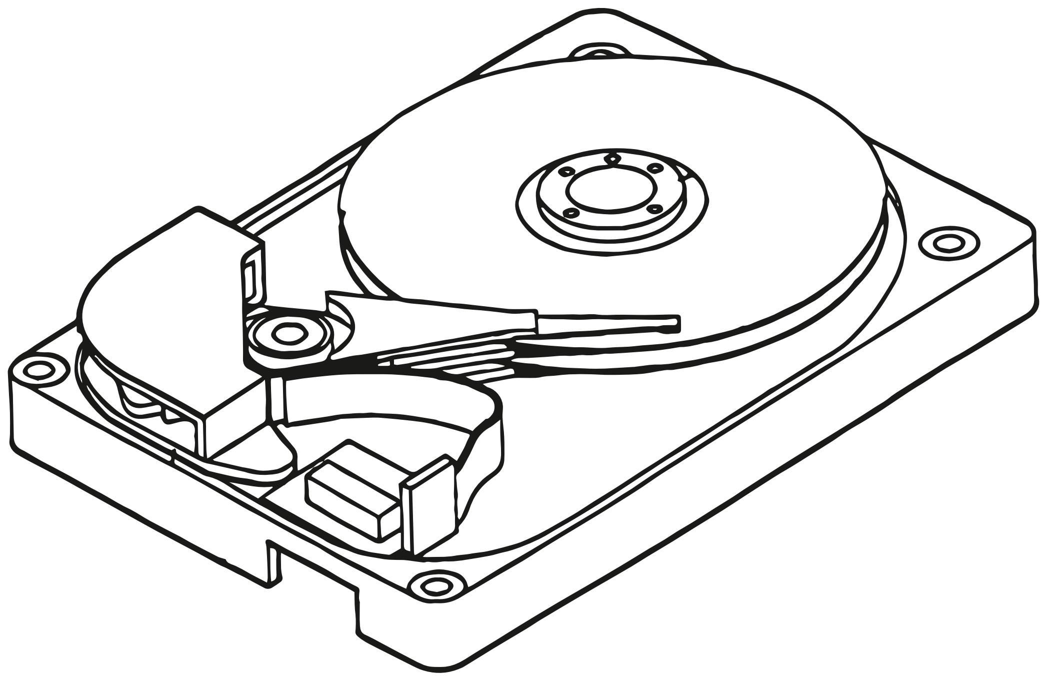
0.68 kg

iPad

The iPad, introduced by Steve Jobs in 2010, is considered to be one of Apple's most revolutionary products. Although tablets had already existed, Apple popularised a new form of modern computing consisting of just one large screen and just a few buttons.

Equipped with iOS, the most fool-proof yet powerful mobile operating system, iPads are used in all kinds of different contexts. This second generation iPad is a personal gift from Wolfgang Härdle, who used this model extensively for teaching.

Storage Systems



Along with the development of faster and more reliable computers, the possibility to input and store digital data has also evolved. If we take into consideration that one punched card, probably the earliest storage system, held 80 bytes, 12.5 million cards would be needed to store one gigabyte. Furthermore, in today's era of petabytes and, believe it or not, exabytes in current computer networks, even the largest of the early storage systems seems dwarfish.

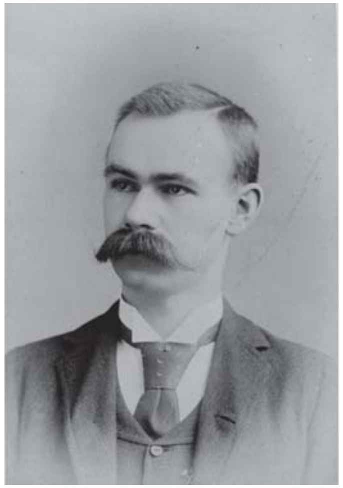


Figure 13: H. Hollerith

The already mentioned *punched card* was firstly developed in the early 19th century, long before the first working electronic computer. As reported by Deitel and Deitel (1986), *Joseph Marie Jacquard* developed the idea in 1801 as an aid to the weaving industry.

As for more modern punched cards, data is stored on them by perforating stiff paper card at predefined positions. These cards are also commonly known as *IBM* or *Hollerith* cards.

Even if *Herman Hollerith* was not, by far, the first person who used perforated paper to control machines, he certainly contributed vastly to the rise of punched cards. Under American law, a national census is obligatory every ten years. Manual calculations in 1880 took more than seven years to complete while the 1890 census was completed after in two and a half years, due to Hollerith's tabulating machines (see Deitel and Deitel (1986)). His main technical innovation is the invention of the tabulator with its electric card reading capabilities as stated by Heide (2009). In 1896 Hollerith founded the *Tabulating Machine Company*, today known as IBM.

As stated by IBM (b), the IBM punched cards had until the late 1920s round holes, twelve rows as punch positions and 45 columns. Due to its popularity in processing data, customers soon required cards with enhanced data storage capabilities. Hence, IBM replaced the round holes with rectangular ones, but kept the dimensions, thus, existing machines did not have to be replaced but just upgraded.

Norberg (1990) describes that punched cards by the mid 1950s also found applications in many industry sectors such as transportation and consumer products. As for the computer era, this popularity implies that punched cards had already been in use for several years and were thus reliable. They were widely used to create computer programs and transfer data onto computers right up until the mid 1970s. Furthermore, businesses were already used to store their data on cards and therefore, punched cards continued to be used instead of other methods such as magnetic tape.

Figure 14: Card Reader

Even programming was done by using punched cards. Often thousands of cards were needed for a single program, called a "deck". After the initial programming, the code still needed to be compiled. This resulted in a second deck of cards in machine code. Of course, computer bugs led to, today difficult to imagine, time-consuming cycles of debugging and punching a substitute for the faulty card.

Punched tape was quite similar to punched cards as it relied on the same way

Figure 15: Punched Tape

of encoding digital data on an analog device. The main difference was that its length was obviously not fixed but variable. While the low information density of paper storage media was a huge disadvantage, its robustness is still distinct in comparison with devices that rely on magnetisation. Preserved cards and tape can still be read today while magnetic tape usually demagnetises over time.

While paper was a viable option to smoothly transfer data, the computers themselves also needed a device to actually store this data. As described by IBM (c), this device also had to be quite fast since more than 150 punched card could be read per minute. Following the invention of magnetic wire that was able to store an audio recording, the very first being by *Valdemar Poulsen* in

1900, IBM started to use magnetic coated plastic tape in the 1940s.

Figure 16: Magnetic Tape

One major challenge was that the tape storage units had to be able to stop at high speeds, often resulting in damaged tape (see Buslik (1952)). Hence, IBM developed a vacuum column to lessen the impact on tapes due to air resistance. This system later became an industry standard and was used for several decades.

However, there were still two major problems as these tapes were, on one hand, quite unreliable and on the other hand, there was not necessarily a standard that described which audio tone translated into which data. The second problem was solved by a hobbyist group that established the *Kansas City Standard* in 1975. Nonetheless, the tape recordings remained so unreliable that early adapters often had to create several copies to make sure that the stored information has not been compromised.

The 8-inch floppy disk was invented by IBM in 1971 to store the computer's initial control program and the microprogram as stated by IBM (a). It was soon adapted as a general storage medium for early personal computers due to its low cost and easy usage. Later on, the size of a typical floppy disk decreased to 5.25 and again to 3.5 inches.

Because early PCs normally did not have a hard disk, PCs were sold with two floppy drives: one to load an application and another usually to store the needed data. Because of low prices, it was finally possible to develop and supply computer software on a comprehensive scale. Hence, computer owners did not have to develop a large part of their software themselves, which led to an increase of user friendliness and the rise of software empires such as *Microsoft*.

Sony, the last producer of floppy disks, terminated production in March 2011 as reported by the Daily Mail (2012). While the private demand for disks dwindled, the floppy disk played a role in the public sector up until 2014: 8-inch floppy disks were still the preferred removable storage method used in a U.S. Air Force nuclear silo (see Daily Mail (2014)).

Microsoft® Windows™ for Workgroups
Operating System
Microsoft
Diskette 1 - Setup
Windows Serie
Diskettenformat: HD (1,44MB)
Version 3.11
ANLEITUNGEN ZUM SETUP:
1. LEGEN SIE DISKETTE 1-SETUP IN DAS LAUFWERK A:EIN
2. GEBEN SIE AN DER MS-DOS EINGABEAUFFORDERUNG A:\SETUP EIN, UND DRUCKEN SIE DIE EINGABETASTE.
DISK ASSY 050-815DV3.11
© 1985-1994 MICROSOFT CORPORATION. ALLE RECHTE VORBEHALTEN.
Microsoft®
MS-DOS 5.0
© Copyright 1991
Microsoft Corporation
Alle Rechte vorbehalten
Dos-Betriebssystem für HIGHSCREEN® Computer
Diskette
5
HIGHSCREEN®


MKE
820H
Quantum Bigfoot CY
9782300

In the early days of computing, the *hard disk drive* was hardly affordable for the average person, but soon became an indispensable piece of hardware. It can be described as a non-volatile storage medium, mainly consisting of one or more rotating platters. The term *non-volatile* means, that the permanent storage of the data is independent of electricity. It is covered with a magnetic material and a moving actuator arm, which is responsible for reading to or writing from the data.

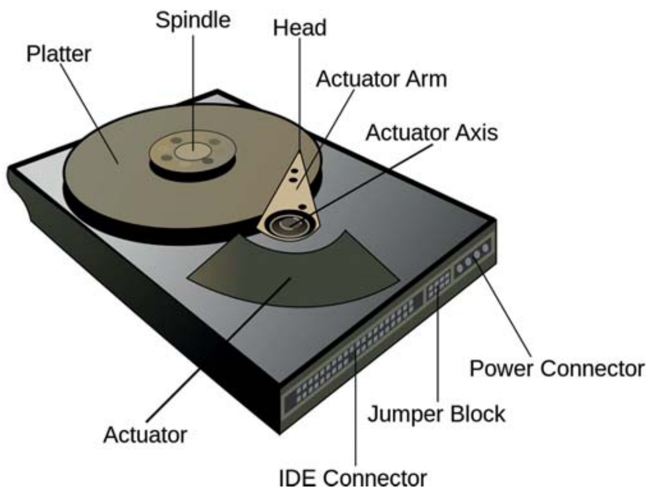


Figure 17: Hard Drive Disk

In contrast to older storage mediums such as magnetic tapes or punched cards, hard disk drives are not configured to read and write data in a sequential order. Instead data is stored and accessed in blocks at random positions on the platter. This has advantages for both the writing speed, since no sorting is necessary and the reading speed, as the information can be accessed in the order it is needed.

The first commercial hard drive was introduced by IBM in 1956, had a storage capacity of 3.75 MB and was sold for $34,500, a massive $9,200 per MB. Early hard disk drives consisted of several platters, with a diameter of 24 inches and required external motors to spin them, they were roughly the size of a washing machine. With technical advances they became smaller over time, decreasing to typically 3.7 or 2.4 inch size today, while prices per GB today lie at approximately $0.03.

At the beginning of the PC-era in the early 1980s, hard drives were still rare and very expensive. With the more widespread use of computers, they became a mass product. Since then an exponential increase in storage power can be observed, while prices per gigabyte have also dropped exponentially. In an analogy to *Moore's law*, this development was dubbed *Kryder's law* by Walter (2005), named after Mark Kryder, the former vice-president of *Seagate*

Corporation. In contrast to Moore's law, which usually refers to a period of two years, the storage density of hard disk drives doubles every 13 months.

While we do not have any data regarding the storage density of hard disk drives, there is historical pricing data compiled by Smith (2011) and Komorowski (2009). A webscraper is utilized as an automated program to download the webpage's content to collect the data from Komorowski (2009). The scraper is available as quantlet CMBhddscrape. For some observations, only the year is given such that we set the month of this datum to January.

There are 274 observations between January 1980 and July 2009 and thus, 355 months of data available. Furthermore, define p_i as the price per gigabyte space and t_i as the month of observation of the hard disk drive i. As an exponential decrease of the price per unit of space is suspected, we linearize the relationship by using a log transformation for the depent variable p_i.

Thus, we assume the model

$$\log(p_i) = \alpha + \beta t_i + \varepsilon_i \tag{2}$$

holds. The results of the corresponding linear regression is shown in Table 2. HC3 standard errors are used to be consistent in case of possible heteroscedasticity. A thorough discussion of the properties of this estimator can be found in Long and Ervin (2000). As a result we can state that we expect a price drop of approximately 5% each month. The high R^2 value of 0.98, the proportion of explained variation, and the statistical significance of the estimated parameters substantiate the findings.

Variable	Estimate	Standard Error	p-value
$\hat{\alpha}$	14.55	0.14	< 0.01
$\hat{\beta}$	-0.05	< 0.01	< 0.01
R^2	0.98		

Table 2: Regression results HDD price, N = 274 CMBhddreg

Figure 18 shows the various data points as a scatter plot and the estimated regression model as a dashed line. Here, we observe that a linear model might not result in an ideal fit as the model periodically either over- or underestimates the price per GB. Hence, a nonparametric approach or a segmented regression might be more suitable but was not performed due to the relatively small sample.

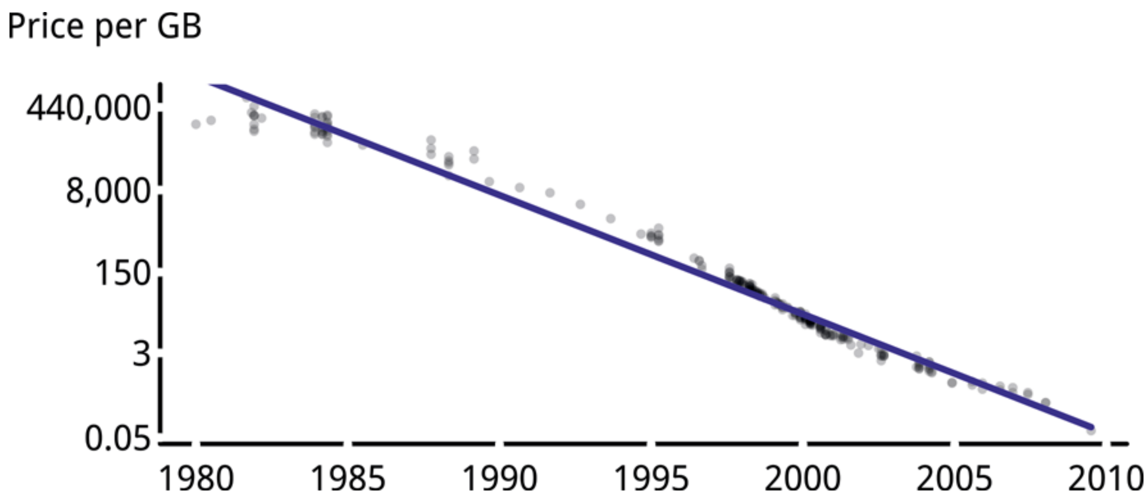


Figure 18: Estimated regression line (blue) and historical observations (scatter)
CMBhddregp

The production and sales of hard disk drives peaked in 2010 with 650 million sold units but they have been declining ever since. Hard drive disks are still a major medium for data storage today, mostly because of their low price. In the last few years they have started to be gradually replaced by *solid state drives*, which are electrically programmed. Solid state drives outperform hard disk drives on both speed and power consumption.

In parallel to the advances in hard drive technology, better and faster internet connections have led to cloud storage services becoming more popular, thus reducing the necessity for private storage devices. Since our digital lives produce massive amounts of data everyday, single storage media have their limitations. Therefore, most online services would not be possible without the existence of smart technologies such as *Hadoop*, which allows for data storage and processing over a system of server clusters.

Future technical ideas and innovations for data storage involve *volume holograms*. They can yield a even higher capacity in a smaller area, since the third dimension is used Coufal et al. (2000).

Symbols

 CD

 Coloured display

 Company

 Gaming machine

 Country

 CPU

 Floppy disk drive

 Year

 Hard disk drive space

 Measures

 Mouse

 OS

 Mechanical principle

 RAM

 Audio capabilities

Tape drive

TV as display

USB connector

Weight

Wireless network

Abbreviations

Abbreviation	Word
ASCII	American Standard Code for Information Interchange
bit	basic unit of information
CD	Compact Disk
CM	Computer Museum
CPU	Central Processing Unit
CRT	Cathode Ray Tube
ČSSR	Czechoslovak Socialist Republic
DDM	East German mark
DM	West German mark
DOS	Disk Operating System
DVD	Digital Versatile Disk
FRG	Federal Republic of Germany (West Germany)
GDR	German Democratic Republic (East Germany)
HDD	Hard Disk Drive
HP	Hewlett-Packard
IBM	International Business Machines
ISDN	Integrated Services Digital Network
LCD	Liquid-crystal-display
Li-Ion	Lithium-ion battery
LvB	Ladislaus von Bortkiewicz Chair of Statistics
MADAS	Multiplication, Automatic Division, Addition & Subtraction
MP3	Moving Picture Experts Group Layer-3 Audio

ni-cad	Nickel–cadmium battery
NYSE	New York Stock Exchange
OS	Operating System
PC	Personal Computer
PDA	Personal Digital Assistant
PET	Personal Electronic Transactor
PPK	Polizeipistole Kriminalmodell (Police Pistol Detective Model)
RAM	Random-Access Memory
ROM	Read-Only Memory
SBus	Smart-BUS
SCSI	Small Computer System Interface
SFB 649	Sonderforschungsbereich 649 "Ökonomisches Risiko" (Collaborative Research Center 649 "Economic Risk")
SPSS	Statistical Package for the Social Sciences
TV	television
UK	United Kingdom
US	United States of America
USB	Universal Serial Bus
USSR	Union of Soviet Socialist Republics
VAIO	"Video Audio Integrated Operation"
VHS	Video Home System
WIAS	Weierstrass Institute for Applied Analysis and Stochastics
WWII	World War II

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